Northern Affairs Program

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Effects of Seismic Activity on the Behavior and Activity of Muskrats on the Mackenzie Delta

Northern Affairs Program

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ABSTRACT

Studies were conducted from January to May 1977 to determine the effects of seismic activity on the normal behavior and activity of muskrats. The Study Area consisted of an 11 ha lake located at 68° 33' N latitude and 134° 27' W longitude in the east central part of the Mackenzie Delta.

The population of the study lake was estimated at 35 muskrats of which 19 were equipped with radio transmitters. Intensive monitoring during April and early May resulted in over 12,000 observations of 16 animals.

Predisturbance activity patterns were characterized by a bimodal daily rhythm with activity peaks at 0800 and 2100 hrs. Muskrats spent approximately 40% of each day foraging from pushups and the remainder sleeping in burrows.

Seismic drilling contributed to a short-term decrease in levels of activity, apparently the result of associated helicopter disturbance. It had no effect however, on either daily activity rhythms or number of daily movements. Post-blasting activity patterns did not differ significantly from predisturbance levels in terms of either mean daily activity or number of daily movements.

Muskrats in burrows or pushups exhibited no behavioral response to clearing or drilling operations but muskrats in burrows were disturbed by helicopters hovering within 12 m. Detonation of 11.3 kg charges elicited a short-term reaction in muskrats in a burrow 12 m away but had no effect at distances of 60 m or more. In another case however, detonation of a 6.8 kg charge resulted in the death of four muskrats in a burrow located 12 m away. Post-mortem examination indicated that death did not result from blast-induced trauma. Empirical observations support a hypothesis that blasting may have released methane gas into the burrow causing death through anoxia.

Seismic activity had no discernible effect on use of muskrat dwellings. Pushup use was not related to either distance from disturbance or distance from bank burrows. Changes in burrow use included a significant increase in use of the burrow nearest a shothole, indicating the absence of an avoidance reaction after blasting.

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1.0 INTRODUCTION

The question of whether or not muskrat populations on the Mackenzie Delta have been and are being adversely affected by oil and gas seismic exploration activities was partially answered in studies conducted during 1976. Summarily, these studies indicated that: (1) population declines were not associated with lakes exposed to seismic exploration, (2) blast injury was confined to animals experimentally exposed to blasts at a distance of 15 m or less and was not sufficient to cause permanent impairment or death and, (3) stress or injury caused by seismic blasting did not result in a measureable decrease in reproductive performance.

During 1977 a second phase of research was conducted dealing with the direct and indirect effects of seismic disturbance on muskrat activity and behavior. This report presents the results of these studies and provides further information on the effects of blast exposure under natural conditions.

The objectives of the 1977 research program were to:

(a) determine the behavioral response of muskrats to seismic drilling, blasting and associated activities

(b) determine whether seismic disturbance disrupts normal activity patterns

(c) determine the effect of seismic blasting on burrows and pushups in terms of their continued use by muskrats and

(d) determine whether animals in natural burrows and pushups incur the same extent of blast injury as ones previously exposed to blasting in artificial situations.

The original objectives also called for surveys to determine the incidence of pushup abandonment on lakes affected by a

seismic program as compared to control lakes some distance away. Consequently during January and February, over 800 pushups were marked on 12 pairs of lakes in and adjacent to the area scheduled for a major exploration program in March and April 1977. Thin ice conditions resulting from an unusually warm winter led to the cancellation of this program however, and the pushup surveys could not be completed. To enable the remainder of the study to proceed, arrangements were made for a 0.5 km section of the original route to be drilled and shot adjacent to the intensive Study Area.

2.0 STUDY AREA

The general study area was located in the east-central part of the Delta, approximately 4 km northeast of the 1976 Study Area (Westworth 1977). Research was centered on an 11 ha lake situated adjacent to Crooked Channel at 68° 33' N latitude and 134° 27' W longitude, approximately midway between Napoiak Channel and the Middle Channel of the Mackenzie River (Figure 1).

The lake is shallow (less than 2 m prior to freeze-up) and steep-sided, with the exception of the north end (Figure 2). During periods of high water it is joined to a system of interconnecting lakes to the south. Flood water, in some years at least, enters the lake over the levee at the north end.

Submerged aquatic vegetation consisted predominately of *Potamogeton richardsonii* and *Myriophyllum exalbescens*, which appeared to grow uniformly over the entire bottom. Emergent vegetation was restricted to a narrow band of *Equisetum fluviatile* and *Carex* sp. along the northeast side. The banks and surrounding terrestrial communities were basically of two types. Well-drained sites were characterized by spruce *(Picea glauca)* climax forest with an understory of alder *(Alnus crispa)* and willow *(Salix* spp.) while low areas supported willow *(Salix* spp.)-sedge *(Carex* spp.) communities.

The study lake is considered to be representative of the smaller Delta lakes. The physiography and vegetation of the region were described in greater detail in an earlier report (Westworth 1977). The lake was ideally suited for the purposes of this study since: (a) it was small, enabling us to study a major portion of the population at one time, (b) it was known, on the basis of previous pushup surveys, to support a good population of muskrats and (c) it was outside of the normal trapping area for local trappers. The entire population of the lake is estimated at 35 animals (Lincoln index) of which 24 were marked during the precensus period.

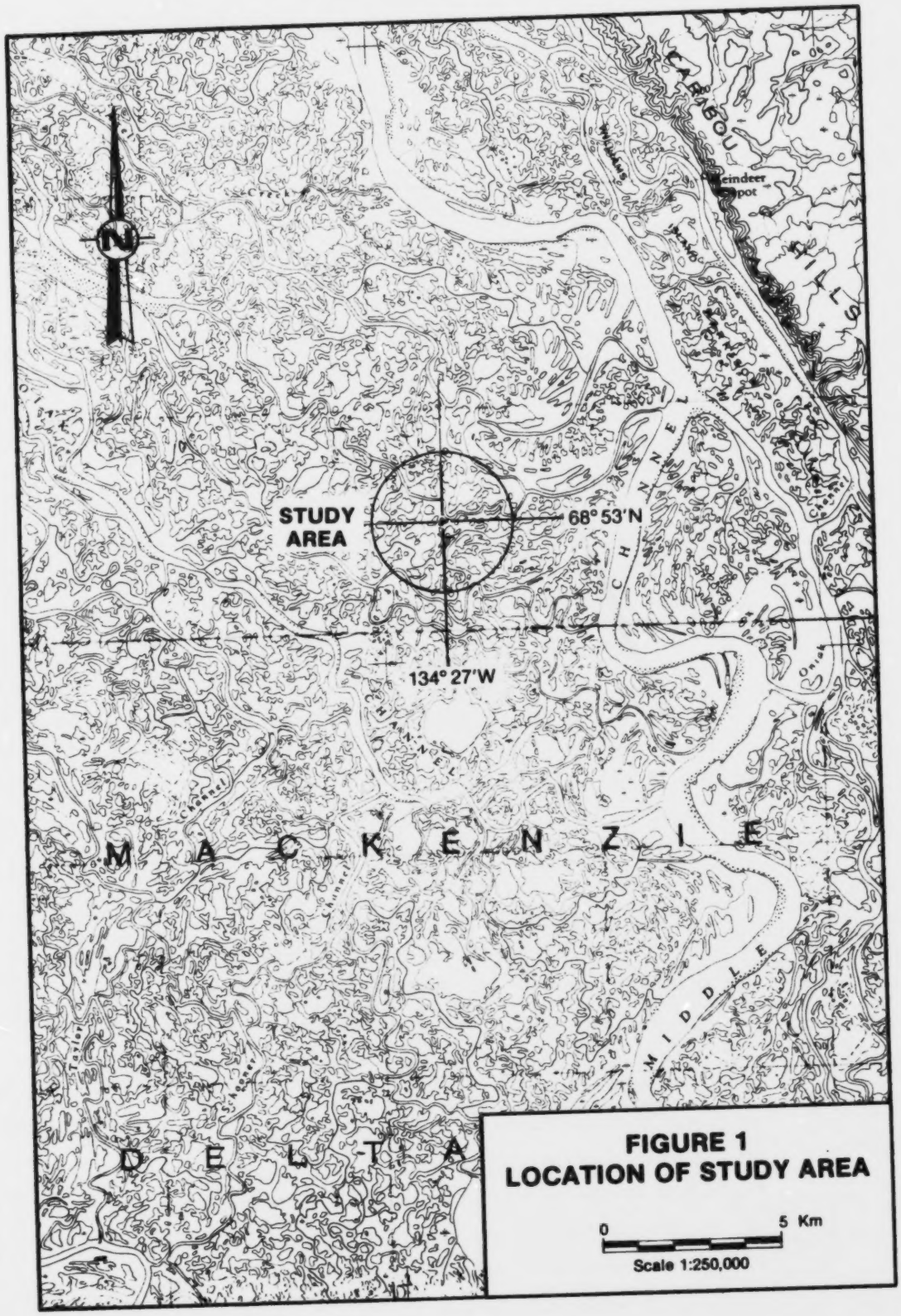
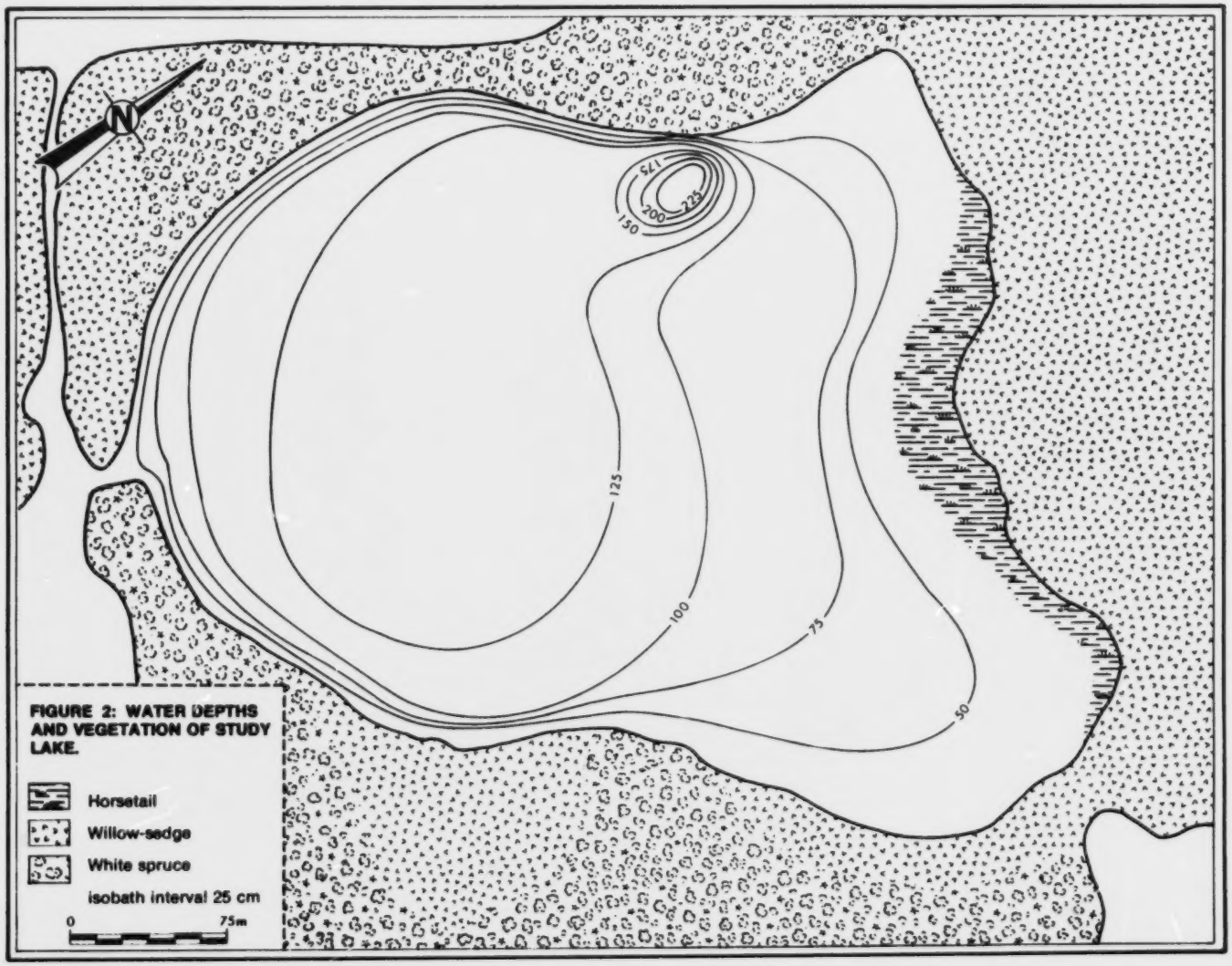


FIGURE 1
LOCATION OF STUDY AREA

0 5 Km

Scale 1:250,000


N
175
225
200
150
125
100
75
50
FIGURE 2: WATER DEPTHS AND VEGETATION OF STUDY LAKE.
Horsetail
Willow-sedge
White spruce
isobath interval 25 cm
0
75m

3.0 METHODS

3.1 Telemetry Equipment

Transmitters used in the study were modified versions of the type described by Wang (1972). They were temperature sensitive and highly directional, emitting a continuous tone with discrete FM frequencies between 88 and 108 MHz. The transmitting units complete with a Mallory RM-1 mercury battery were rendered biologically inert and waterproof by encasing them in a mixture of beeswax and paraffin. The sealed transmitters weighed approximately 20 g which amounted to 1.7 - 2.7% of the body weight of the animals. The maximum range of the transmitters through the air was about 30 m.

The receiver used was a Superscope (Model CR 800) cassette-recorder. Receiving antennas consisted of 300 ohm T.V. antenna wire looped around pushups and burrows in the manner shown in Photo 1. Antenna leads were relayed to a centrally located, heated tent where they fed into a 22 outlet panel box. To minimize inductance between leads, the terminal 30 m consisted of 75 ohm shielded cable connected to the 300 ohm antenna wire with a matching transformer. An F59 push fitting enabled the observer to easily connect the receiver to any of the 22 antennas (Photo 2).

3.2 Techniques

The intensive study lake was first visited on February 13 during the course of pushup surveys. At this time the snow cover on the lake averaged 30 cm and no overflow conditions were noted. Pushups were located by systematically walking back and forth across the lake, probing mounds on the surface of the snow with a narrow stainless steel rod affixed to a wooden handle (Photo 3). Each pushup was marked with a numbered flag and recorded as being active or abandoned, depending on whether the plunge hole was open (indicating frequent use by muskrats) or frozen.

Photo 1. Telemetry antenna wire in place over an exposed pushup. The pushup was then recovered with snow to restore insulation. Bank burrows were wired in the same manner.

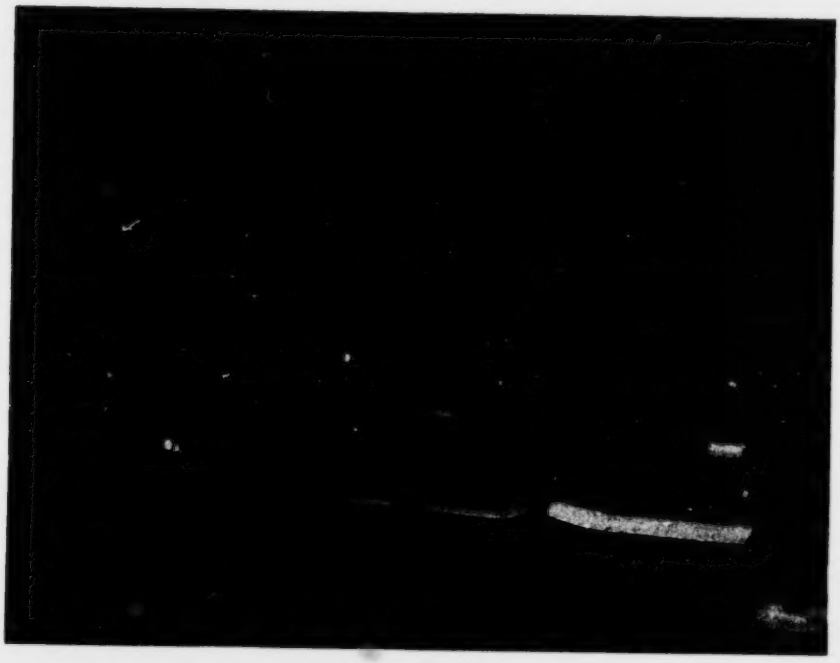


Photo 2. Antenna panel and receiver housed in centrally located tent.

Photo 3. Pushups on study lakes were located and marked prior to heavy snow accumulation. The long, metal rod was inserted through the pushup to determine whether the underwater entrance was being kept open by muskrats.

Photo 4. Livetraps set at pushups were encased with styrofoam insulation and covered with a thick layer of loose snow.

Livetrapping began on 27 March and was completed on 7 April, being partially hampered by temperatures ranging to -39° C. The methods, which are described in detail in a previous report (Westworth 1977), involved probing pushups to be livetrapped with the steel rod to determine the location of the pull-out platform. A small (10 - 12 cm diameter) hole was then carefully cut into the side of the pushup, adjacent to the platform and a 15 x 15 x 47 cm single door, National brand livetrap set flush with the opening. Traps were encased on all sides with 7.5 cm thick styrofoam insulation, after Hawley and Hawley (1975), and openings or cracks were sealed with slush and wet pushup material (Photo 4). After each 8 to 12 hour trap check, the pushup was recovered with a thick layer of light snow to restore insulation.

A total of 24 muskrats were livetrapped, of which 19 were equipped with radio transmitters. Animals were selected on the basis of age, sex and proximity to the proposed seismic line in a manner intended to be representative of the overall population. The remaining muskrats were measured, weighed, aged, sexed, ear tagged (National Size 1, Style 1005) and released. Sex was determined through palpation of the external genitalia. Ages were assigned as adult or juvenile based on size, overall appearance, pelage, and appearance of the external genitalia and verified following the study by post-mortem examination of teeth and reproductive tracts.

3.2.1 Implanting Transmitters

Muskrats selected for telemetry studies were transported by snowmobile 5 km to a heated trailer. Surgery was conducted within six hours of capture. Animals were anaesthetized with sodium pentobarbitol (40 mg/kg body weight) injected intraperitoneally. Required dosages and response times varied considerably although most of the animals were sufficiently under within five minutes. Surgery involved making a 3 - 4 cm long

incision through the skin and abdominal wall along the linea alba, inserting a sterilized transmitter into the peritoneal cavity, and closing the incisions with silk suture material (Photo 5). The resulting wound was treated with a topical antibiotic to reduce the likelihood of infection. The animal was then returned to its cage and placed in a warm area of the trailer to recover. Recovery normally began in less than one hour and in every case the animal appeared normal, active and ready for release the following morning. The frequency of the implanted transmitter was recorded following surgery and again at the time of release.

3.2.2 Antenna Set-up

Following their release, at the point of capture, the muskrats were given several days (mean = 10 days) to recover from surgery prior to intensive monitoring. The procedure involved initially monitoring the movements of several radio-marked animals on foot to locate pushups and burrows in use by specific family groups. Of the three groups intensively monitored, two were located on the side of the lake adjacent to the proposed seismic line while the third served as a control on the side opposite the line.

Once all known burrows and pushups were located, the snow was carefully removed, the antenna wire put in place and the dwelling again covered with a thick layer of fresh snow. Since the number of active burrows and pushups (30) in use by radio-marked muskrats exceeded the capacity designed for the antenna system (22), it was necessary to group several pairs of closely spaced pushups by looping the antenna wire in series. This enabled us to locate an animal virtually every time but in some cases did not allow us to distinguish between individual pushups.

Photo 5. Sutures being placed in skin of anaesthetized muskrat after implantation of transmitter. Regrowth of underfur was pronounced one week after surgery and essentially complete after one month.

3.2.3 Monitoring

Monitoring involved systematically searching for frequencies of radio-marked animals on each of the 22 antennas. During the pre- and postseismic monitoring periods, readings were taken at ½ hour intervals 24 hours a day by three observers working in shifts. Tag number, frequency reading and activity code were entered opposite the respective locations on field data forms.

The transmitters were highly directional with slight changes in the orientation of the radiating coil relative to the antenna wire causing discernible fluctuations in the radio signal. Observations of both captive and free-ranging muskrats prior to the start of the study enabled us to identify the signal changes associated with activities such as walking, turning, grooming or swimming. During routine monitoring, one of the following three activity codes were recorded for each animal, based on a 10 - 15 second period of observation:

C - stationary
M - moving (walking, grooming etc.)
S - swimming

3.2.4 Seismic Test Blasts

As indicated earlier, the study was originally intended to coincide with a normal seismic exploration program conducted by Imperial Oil Ltd. Their permit called for a conventional single line operation consisting of six intersecting lines covering an area of approximately 120 km^2. Lines would be cleared to a width of 10 m (33 ft) along which 18.3 m (60 ft) deep shot holes would be drilled at 122 m (400 ft) intervals. Holes were to be loaded with 6.8 - 11.4 kg (15 - 25 lb) charges of Geogel. Shot points would conform to the regulation 12 m (40 ft) separation from lakes and channels. Thin ice condi-

tions (minimum 40 cm) in Tumma and Crooked Channels caused Imperial Oil to cancel the program on March 9.

Following cancellation of the program, contingency arrangements were made to drill eight experimental shot holes along the intensive study lake with a helicopter portable drill rig. The procedures involved, differ substantially from the more common track mounted drilling operations although helicopter drilling has been employed quite extensively on the Delta in the past. These procedures are described in Section 4.2.

4.0 RESULTS

4.1 Introduction

Twenty days of intensive monitoring were conducted during the period 10 April to 3 May. Of these, 13 days corresponded to the predisturbance period, 2 days to the post drilling period and 5 days to the postblasting or postdisturbance period.

This resulted in 12,408 observations of 16 radio-equipped muskrats for an average of 775.5 observations per muskrat. Three of the transmitters implanted ceased functioning during the recovery period prior to intensive monitoring. Of the 16 that did function, 12 continued to provide data until the end of the study, one (455) failed on the 16th day and three (460, 465 and 471) failed on the 15th day, following blasting.

The spatial and social relationships revealed by the telemetry data indicated three distinct social groups. Since various authors (Errington 1963, Westworth 1974) have reported that young muskrats normally remain with the pair of parental adults during their first winter, these groups are referred to here as family groups.

Home ranges, defined in this report as the area encompassing all pushups and bank burrows used by each family group, are shown in Figure 3. In most cases, all pushups and burrows within a particular home range were used by all members of the family group. Within each home range however, there was a tendency for individuals to make preferential use of particular pushups. Spatial use of home ranges will be described in detail in a later publication.

Family home ranges were mutually exclusive and generally did not overlap. Exceptions involving use of a dwelling by members of more than one family group amounted to less than 0.001% of the observations.

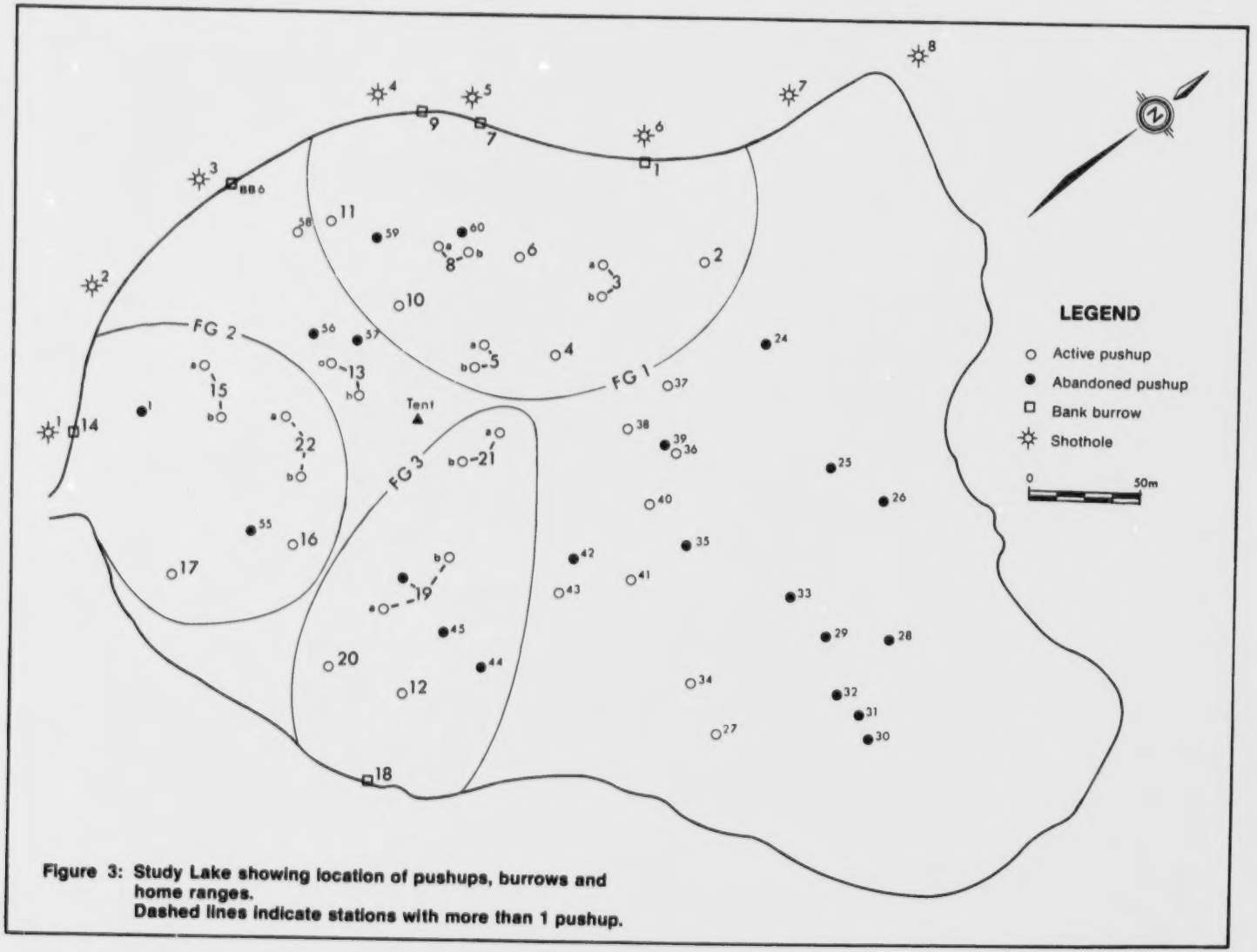


Figure 3: Study Lake showing location of pushups, burrows and home ranges.
Dashed lines indicate stations with more than 1 pushup.

4.2 Behavioral Responses of Muskrats during Drilling Activities

The drilling, which began on April 25, was interrupted by inclement weather and not completed until the afternoon of April 26. The first stage of this process involved hand clearing each drill site of tall trees and shrubs to enable the helicopter to lower the drill rig into position. Two men with chain saws took approximately 30 minutes to clear each site.

The drill, a reverse circulation, forced air helidrill, was then moved into position in three pieces (Photo 6). The first unit comprised the base with the compressor, followed by the drill tower and motor and finally a utility box containing fuel, drill stems and explosives. When the drill was moved to a new site, the tower was removed first to a temporary location on the ice to enable the base to be placed over the previously flagged shot point. Although the helicopter crew was instructed to use an adjacent lake for staging, they apparently found it necessary to land on the Study Lake in several instances.

The procedure called for 10 cm diameter holes to be drilled to a depth of 18.3 m (60 ft), however, the presence of a hard clay pan prevented air rotary drilling to the full depth in four of the holes. Shothole (SH) 1 was 14.6 m (48 ft), SH 4 was 18.0 m (59 ft) and SH 7 and 8 were 16.8 m (55 ft) deep. Above the clay pan the materials consisted of frozen silts interbanded with thin lenses of sand and ice. Actual drilling of each hole took approximately 25 minutes and involved five drill stem changes.

The location of the shotholes conformed to the intended 61 m shot point separation although this alignment was pre-positioned such that holes were drilled directly behind three of the bankburrows (Station 1, Station 7 and Station 14). SH 1-4 were loaded with 6.8 kg of Geogel and SH 5-8 were

Photo 6. Air rotary drill being moved into position by helicopter.

loaded with 11.3 kg. Partial collapse of the sidewall or an obstruction in SH 3 prevented the explosive from being inserted beyond a depth of 2.4 m. All of the holes were then tamped (partially filled with dirt) in accordance with normal seismic procedure.

During the clearing and drilling operation the locations of all radio-marked muskrats were recorded at 10-15 minute intervals. As well, those animals in burrows and pushups closest to each shot point were monitored continuously and the resulting information recorded on tapes. One of the researchers kept the two who were monitoring muskrat activity informed of each stage of the drilling operation by means of two-way radios. In this way it was possible to document the precise responses of muskrats to each type of disturbance associated with seismic drilling.

The behavioral responses of six muskrats located in a bank burrow (Station 1) on the west side of the lake are shown in Figure 4 . Most of the animals were inactive and interpreted as sleeping during the predisturbance period. Disturbance associated with clearing the drill site, either immediately behind Station 1 or 111 m away at SH 7, caused no discernible change in activity of these animals. Even momentary reactions did not appear to result from the falling of several large trees close to the bank burrow. Consistent responses were apparent however, during helicopter movement of the drill rig. These responses tended to be specific and were associated only with low level (<30 m) hovering near the bank burrow. For example, when the rig was moved from SH 5 to SH 6 behind Station 1, no movement was detected when the first piece of the drill was set in place. During the second trip however, the crew had some difficulty lowering the drill tower onto the base and hovered over the site for 30 seconds. All six muskrats began moving around in the burrow. A similar response

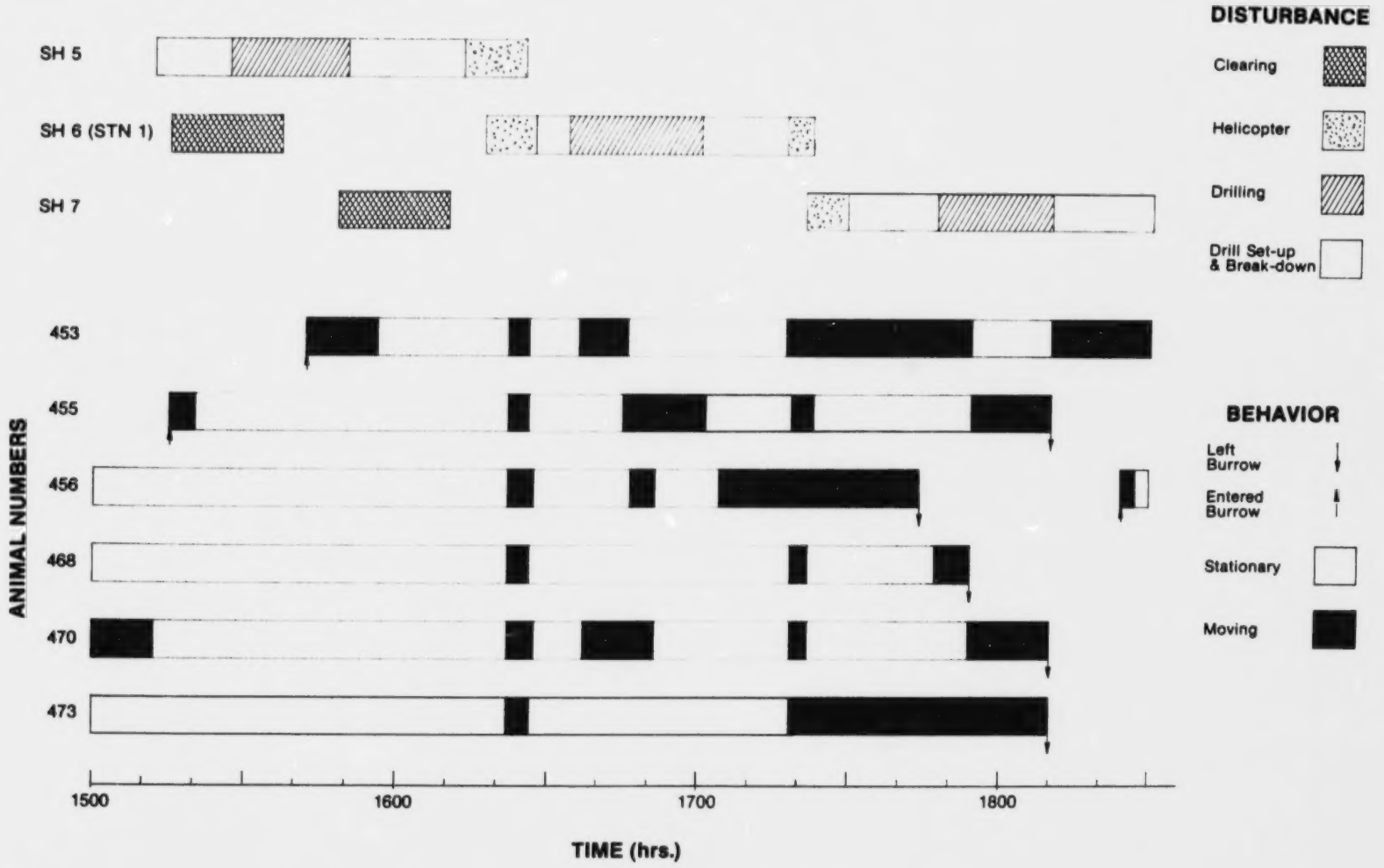


Figure 4: Behavior of muskrats at Station 1 during seismic drilling operations.

to hovering occurred again when the drill was removed from this site. Muskrats were apparently not bothered by helicopter activity more than 100 m away. Results obtained while monitoring two animals at Stations 7 and 14 on 25 April agree closely with the above observations.

While some movement took place during the period of drilling (Figure 4), the responses were less consistent and did not appear to be elicited by a particular aspect of the operation. These movements may reflect a residual response to the helicopter disturbance.

In summary, the results of monitoring 10 muskrats in three bank burrows exposed to seismic drilling activities indicate a low overall level of disturbance, related primarily to operation of a helicopter used in drill transport. Animals reacted consistently to low level hovering near the burrow by walking around but in the majority of cases the period of response did not exceed five minutes and in no instance did this disturbance cause an animal to leave the burrow. Movement of animals out of the burrow (Station 1) at around 1800 hrs, as indicated in Figure 4, was consistent with the normal daily activity pattern.

4.3 Behavioral Responses of Muskrats during Seismic Blasting

The charges were detonated in seven of the shotholes between 1300 hrs and 1600 hrs on 28 April. The holes were shot in reverse order beginning with SH 8. Like the drilling, the period of blasting was scheduled to coincide with the period when a majority of muskrats were in bank burrows and consequently closest to the point of impact. SH 5, which was located behind Station 7, was not detonated to enable us to determine whether animals occupying Station 1 at the time of the blast would respond to the disturbance by preferentially using bank burrows farther from the shot point. For

safety reasons this charge was detonated at the completion of the study.

Charges were detonated sequentially at 10-20 min. intervals to simulate a normal seismic operation. Behavior of radio-marked muskrats occupying stations closest to the shot points were monitored in the same manner as described previously for drilling activities.

The responses of six muskrats at Station 1 and three muskrats at Station 14 during the period of blasting were similar (Figures 5 and 6). In both cases there was no detectable response to blasts of either 11.3 kg or 6.8 kg at shot holes located 111 m or more away from the burrow. The animals did react, however, to detonation of the charges immediately behind the burrows.

At Station 1, four previously stationary animals suddenly began moving immediately after the blast. This period of movement only lasted 6-7 minutes. A fifth animal (456) began moving prior to the blast so the response is less clear. Muskrat No. 452 left the burrow at the time of the blast and went to Station 7 until 1550 at which time the blasting was complete. (There was disagreement between two observers as to whether this animal left immediately before or just after the charge was detonated.) Movement of muskrats out of burrows following periods of inactivity or sleep was almost invariably preceded by several minutes of grooming and/or walking movements within the burrow. The absence of such a movement period in this case further suggests that the exit of No. 452 was blast related. In contrast, No. 468 was apparently sleeping deeply throughout the period of monitoring and demonstrated no reaction to any of the blasts.

The blast behind Station 14 occurred at 1535 hrs. Prior to the blast, muskrats No. 465 and 471 were inactive. The trans-

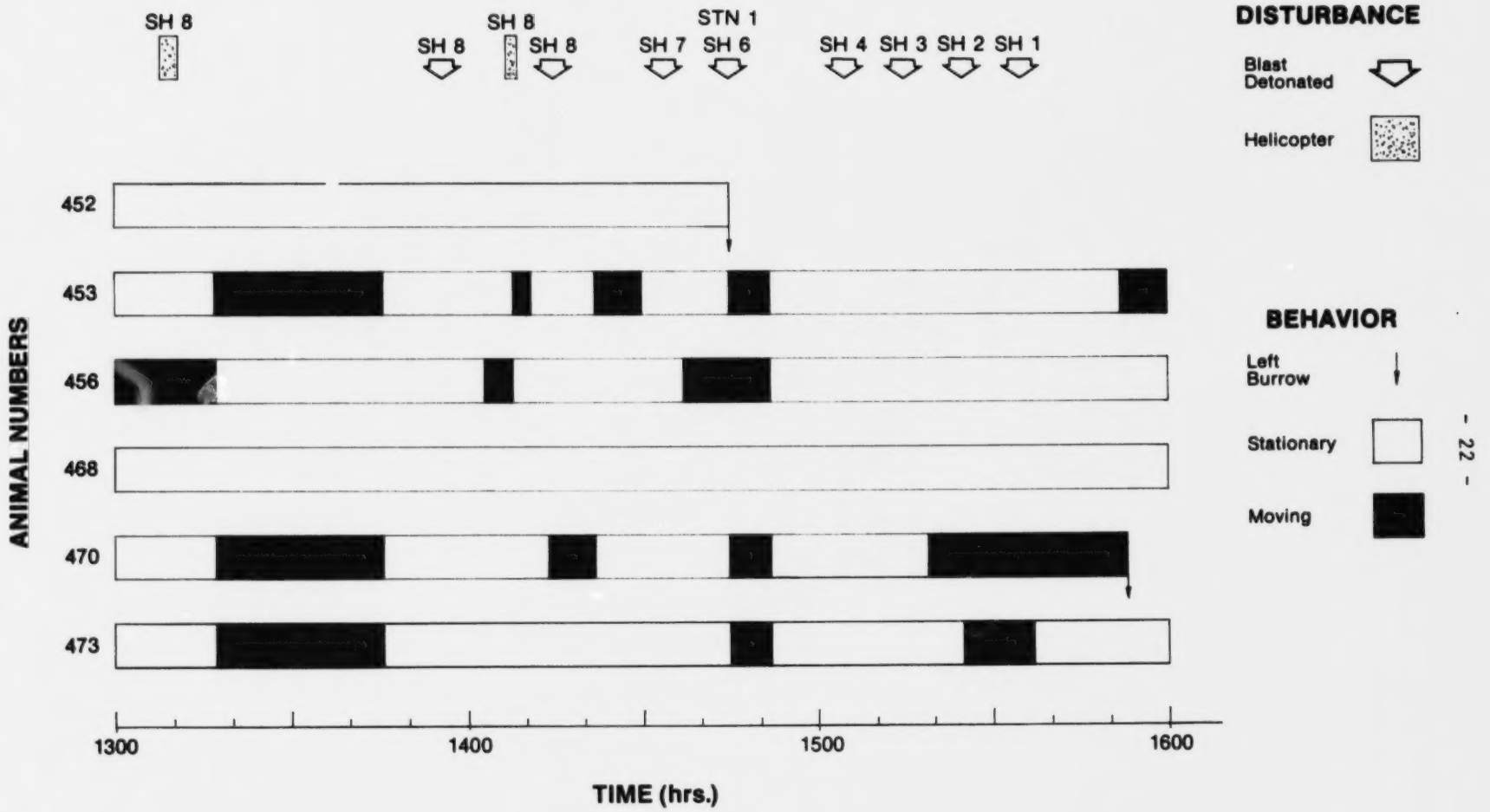


Figure 5: Behavior of muskrats at Station 1 during seismic blasting.

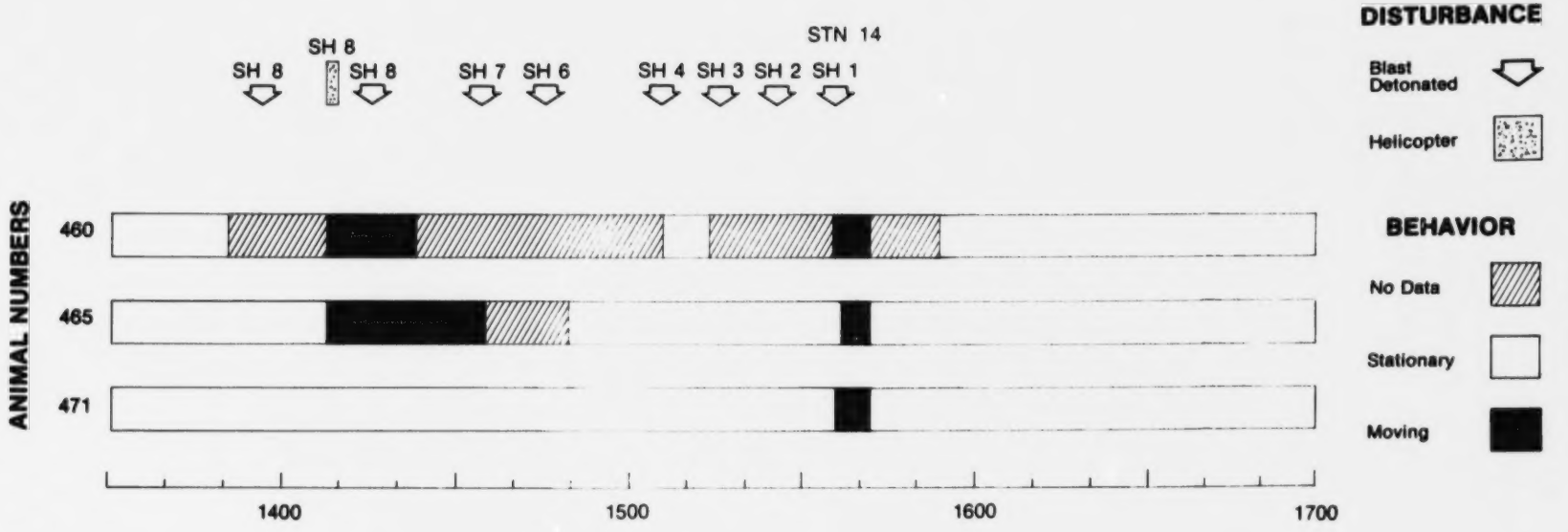


Figure 6: Behavior of muskrats at Station 14 during seismic blasting.

mitter in No. 460 had malfunctioned throughout the study, emitting a weak signal that was only detected intermittently, presumably when the animal was oriented in a particular plane or occupied certain parts of the burrow. No. 471 reacted suddenly to the shot and began moving around in the burrow. No. 465 and 460 also began moving throughout the burrow although 465 did not begin moving until one minute after the blast. In each case movement was only detected for 4 or 5 minutes. Between 1645 and 1715 hrs the tonal frequency received from all three muskrats changed unmistakably to that emitted by cold transmitters, indicating that these animals were dead.

4.3.1 Behavior of Muskrats in Pushups in Relation to Seismic Blasting

The movements and activity of a number of muskrats occupying pushups during the period of blasting were monitored, although at a less intensive level than for those in burrows.

Muskrat No. 455 was particularly active during this period, changing location at least seven times after leaving Station 1 prior to the onset of blasting. It was recorded in Stations 3, 5, 6 and 8 although it remained at Station 5 during all five blasts on the west side of the lake. None of the movements appear to be associated with the times of blasting.

Muskrats 469 and 451 were located at Station 17 between 1300 and 1500 hrs where activity checks at 10-15 minute intervals indicated they were sleeping. No. 469 left this pushup at 1501 and swam to Station 15 which was approximately 80 m closer to the area of disturbance. It remained at this station apparently engaged in feeding and foraging until 1655 when it moved to Station 16. At the time that SH 3 was detonated (1515 hrs) 120 m away it was swimming underwater close to Station 15. It was also being continuously monitored during the period in which SH 2 was detonated approximately

70 m away 18 minutes later. It remained completely stationary until 30 seconds after the blast when it began grooming. No. 451 remained at Station 17 until 1560 hrs when it too moved to Station 15.

The above observations indicate that the behavior of muskrats in pushups as close as 70 m to shot points is unaffected by blast disturbance. These observations are probably applicable to most circumstances encountered in normal seismic operations since pushups on the Mackenzie Delta are only rarely located within 40 m of shore. Movements of muskrats at more distant stations on the east side of the lake similarly appeared unrelated to the blasting activity. Prior to blasting, all four muskrats (Nos. 458, 462, 463 and 464) using Station 16 were in the burrow. During the period of blasting, two animals undertook feeding excursions which brought them closer to the area of disturbance, No. 458 went to Station 19 while No. 463 went to Station 21.

4.4 Effect of Seismic Disturbance on Muskrat Activity Patterns

The preceding sections dealt with the short-term behavioral responses of muskrats to seismic drilling and blasting operations. Also of concern are longer-term changes in daily activity patterns. Significant changes in the amount of time expended on essential activities such as feeding and resting must be considered potentially deleterious, particularly in a species like the muskrat that exists within rigidly defined environmental limits. During late winter the physical constraints associated with an increasing ice thickness and diminishing food supply are at their maximum. The increasing energy requirements expected as animals forage over greater distances for vegetation of decreasing quality are further increased as muskrats begin entering reproductive condition in late March and April.

The principal activities of muskrats at this time of year are feeding and sleeping and virtually the entire day is directed toward these two activities. Intraspecific strife, which is so apparent during mating and during the spring and fall dispersal periods (Westworth 1974), appears to be absent during the winter. Territorial boundaries maintained during the ice-free period become fixed after freeze-up and the limits of home ranges become defined by the location and dispersion of pushups or breathing holes. Occasional instances of home range overlap detected during this study appeared to be accepted with a high degree of tolerance.

The specific behavior and activity of muskrats using pushups and bank burrows, based on records of continuous monitoring during April and early May, will be analyzed in a later report. For the purpose of examining the relationship to seismic disturbance, it is only necessary here to note that use of pushups is predominately associated with feeding and use of burrows with sleeping or resting. The radio telemetry data therefore provides a reasonably accurate picture of the amount of time devoted to these two major activities before and after seismic disturbance. Data are not included in this section for Family Group 2 because of the unusual situation in which two muskrats (469, 451) used only pushups while the rest (460, 465, 471) used only the bank burrow and because the latter died following the blast in SH 1 on April 28.

Two indices of muskrat activity are considered in this section. The first, percent of time active, refers to the proportion of time that muskrats were out of the bank burrow and therefore engaged in feeding or travelling. The number of daily movements, as indicated by changes in location during the half hour checks was used as a second index of activity.

4.4.1 Daily Activity Patterns

Most animals have been shown to undergo 24-hour activity rhythms in response to both fluctuating environmental stimuli and endogenous physiological rhythms (Aschoff 1963, 1966). Muskrats as well are known to demonstrate predictable daily (circadian) rhythms (MacArthur 1977, Van Horn 1975).

A combined daily activity graph plotted for seven muskrats from Family Group 1 and four muskrats from Group 3 indicates that activity is distributed into two major periods (Figure 7). During the predisturbance period, activity peaks occurred at approximately 0800 hrs and 2100 hrs. The activity periods are of approximately equal duration although the second peak is slightly higher.

The bimodal activity pattern remained much the same after disturbance. The only apparent differences are a slight decrease in height of the activity peaks and an increase of approximately one hour in the temporal spacing of the peaks.

The proportion of daylight activity, here defined as the proportion of observations in which muskrats were active between sunrise and sunset, increased slightly from 73% during the predisturbance period to 86% during the postdisturbance (postblasting) period. It is apparent from Figure 7 that this change is not associated with shifts in the diel activity rhythm but rather with increases in the amount of daylight and the overall level of muskrat activity

4.4.2 Overall Activity Patterns

Some pronounced changes in the overall level of muskrat activity occurred during the study for both Family Groups 1 and 3. The extent to which these changes reflect random fluctuations or the effect of possible seismic disturbance factors is confounded by the interacting influences of weather, photoperiod and physiological changes related to reproduction (Figure 8).

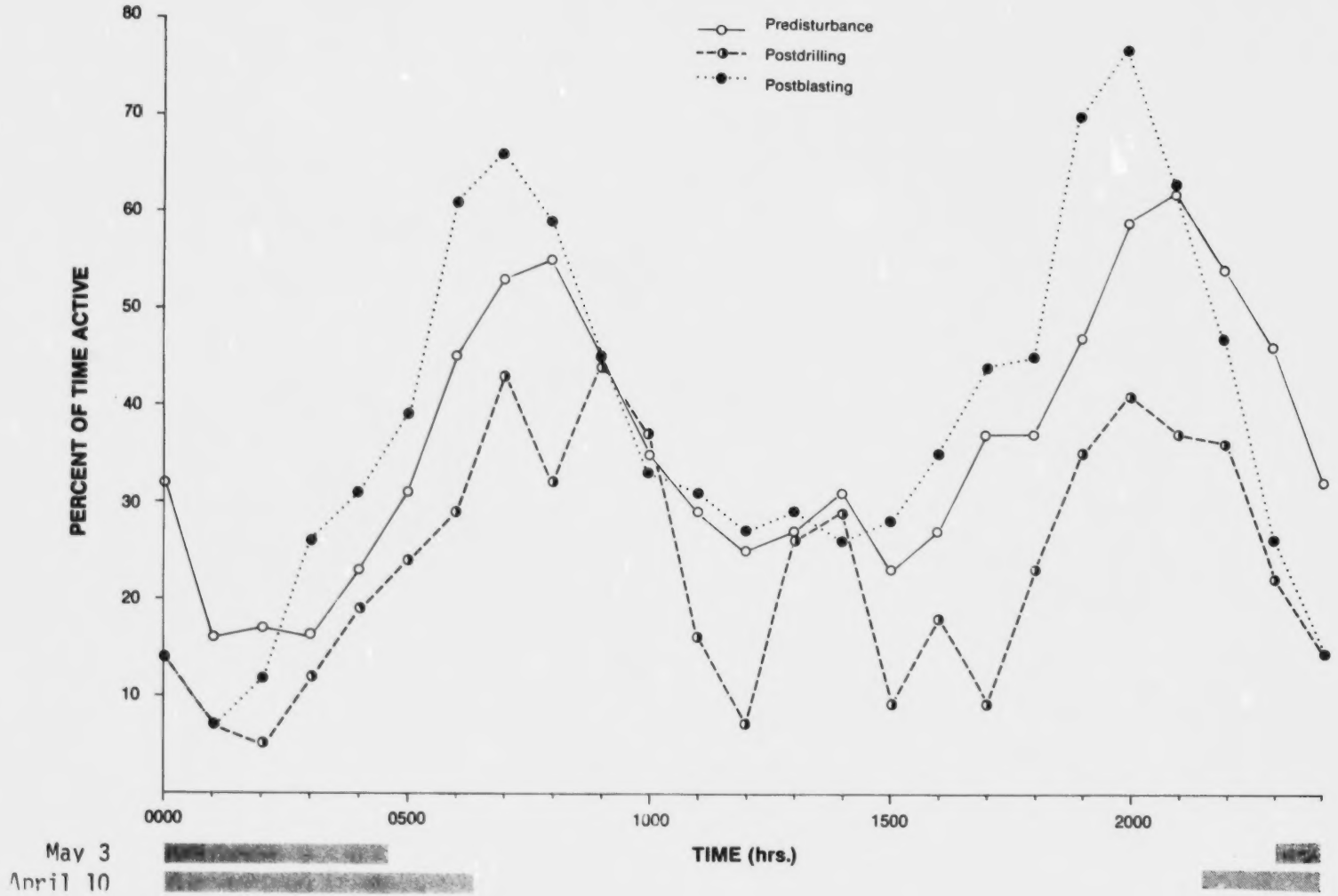


Figure 7: Combined diel activity for 11 muskrats from Family Groups 1 and 3. Darkness

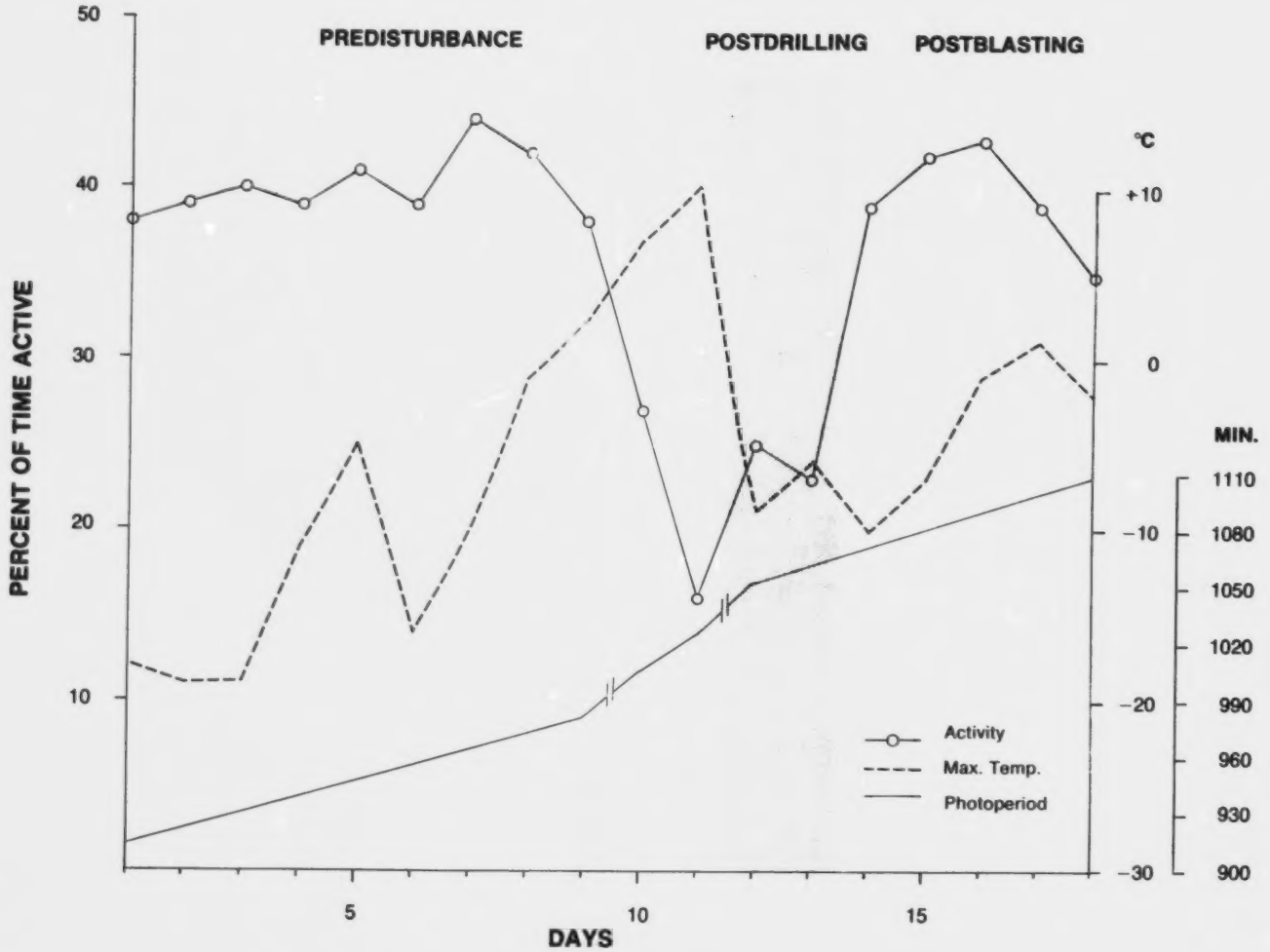


Figure 8: Average activity levels of 11 muskrats in relation to disturbance, photoperiod and maximum temperature.

The effects of these various independent variables were analyzed with the use of analysis of covariance (MTS/SPSS, version H, ANOVA subprogram). This procedure is equivalent to multiple regression analysis employing some categorical (or dummy) variables. Regression procedures are used to remove extraneous variation in observed levels of muskrat activity due to various *covariates* as well as showing the decomposition of explained variance due to the *main effects*.

The covariates used in the analysis include: maximum, minimum and mean daily air temperature, daylight (minutes between sunrise and sunset) and mean daily barometric pressure. Although maximum and minimum temperature, as well as general weather observations were recorded daily on the Study Area, all weather data used in the analysis were obtained from the Inuvik weather station since it was felt that the greater reliability in measurement provided by the latter more than offset local climatic differences between the two areas.

The independent variables defined in the analysis as main effects were: age, sex, family group and state. State refers to the three categories of disturbance (1 - predisturbance, 2 - postdrilling, 3 - postblasting).

Precipitation was also originally included as an independent variable, however, an unusual situation existed wherein greater-than-trace amounts of snowfall occurred only during the postdrilling period. This resulted in a perfect correlation between two independant variables, a situation referred to in regression as multicollinearity, which prevents the analysis from being computed (Nie *et al.* 1975). In order to determine the explained variance due to state, it was therefore necessary to drop precipitation from the analysis.

The results of the analysis of covariance, in percent of time active, are presented in Table 1 . The F tests indicate signifcant ($P < 0.05$) effects due to daylight, state and family.

Table 1. Analysis of covariance for proportion of time active.

```
* * * * * * * * * * A N A L Y S I S   O F   V A R I A N C E * * * * * * * * * *
            ACTIVE   % OF TIME ACTIVE
         BY STATE
            FAMILY
            AGE
            SEX
       WITH MAXTEMP  MAXIMUM TEMPERATURE C
            MINTEMP  MINIMUM TEMPERATURE C
            MEANTEMP MEAN TEMPERATURE C
            DAYLIGHT NUMBER OF MINUTES OF DAYLIGHT
            PRESSURE MEAN DAILY PRESSURE ML
* * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
```

SOURCE OF VARIATION	SUM OF SQUARES	DF	MEAN SQUARE	F	SIGNIF OF F
COVARIATES	5850.168	5	1170.033	14.050	0.000
MAXTEMP	277.565	1	277.565	3.333	0.070
MINTEMP	128.314	1	128.314	1.541	0.216
MEANTEMP	132.245	1	132.245	1.588	0.209
DAYLIGHT	497.299	1	497.299	5.972	0.016
PRESSURE	93.511	1	93.511	1.123	0.291
MAIN EFFECTS	3209.644	5	641.969	7.709	0.000
STATE	2644.500	2	1322.250	15.879	0.000
FAMILY	451.966	1	451.966	5.427	0.021
AGE	1.260	1	1.260	0.015	0.902
SEX	10.799	1	10.799	0.130	0.719
2-WAY INTERACTIONS	1750.000	8	218.750	2.627	0.010
STATE FAMILY	426.569	2	213.284	2.561	0.080
STATE AGE	103.705	2	51.853	0.623	0.538
STATE SEX	314.799	2	157.400	1.890	0.154
FAMILY SEX	923.867	1	923.867	11.094	0.001
AGE SEX	227.751	1	227.751	2.735	0.100
3-WAY INTERACTIONS	245.512	4	61.379	0.737	0.568
STATE FAMILY SEX	158.008	2	79.004	0.949	0.389
STATE AGE SEX	181.697	2	90.848	1.091	0.338
EXPLAINED	11055.523	22	502.524	6.034	0.000
RESIDUAL	14323.422	172	83.276		
TOTAL	25378.945	194	130.819		

198 CASES WERE PROCESSED.
3 CASES (1.5 PCT) WERE MISSING.

Maximum temperature has a significance of 0.07. The only effect judged highly significant ($P < 0.01$) was state which accounted for almost one fourth of the explained variance. Of the interactions tested, a significant effect was only found for family and sex.

The fact that the effect of state was found to be significant means only that the mean of at least one category of state differed from the grand mean. By examining the pattern of variation by means of a multiple classification analysis (Table 2), it is apparent that virtually all of the variance due to disturbance occurs during the postdrilling period. The second last column in the table gives the deviation of the mean from the grand mean for each category when adjusted for the other variables. In this case the deviation for postdrilling is -11.54 while the deviation for the predisturbance and postblasting periods are almost the same at 1.16 and 2.18 respectively. Finally, the coefficient of determination (R^2) in the last column indicates that about 36% of the variation in muskrat activity is explained by the additive effects of the covariates and main effects tested.

When the number of daily movements are tested in the same way, the results differ substantially (Table 3, Figure 9). Again daylight is the only covariate found significant. However, among the main effects; family group, age and sex proved to be highly significant ($P < 0.001$). State apparently had no effect on the movement of muskrats. The multiple classification analysis (Table 4) suggests a slight stepwise increase in number of daily movements during the three periods of disturbance. Significantly fewer daily movements apparently occurred among adults, among females and among individuals from Family Group 3. The R^2 value indicates that only about one quarter of the variation of the dependant variable is explained by the independent variables tested.

Table 2. Multiple classification analysis for proportion of time active.

```
* * *   M U L T I P L E   C L A S S I F I C A T I O N   A N A L Y S I S   * * *
          ACTIVE   % OF TIME ACTIVE
       BY STATE
          FAMILY
          AGE
          SEX
       WITH PASTPM  PASTURE TEMPERATURE C
            PIRIPM  PIRIPM TEMPERATURE C
            RELATPM  RELATIVE TEMPERATURE C
            DAYLIGHT  NUMBER OF MINUTES OF DAYLIGHT
            PASSQUST  DEAD DAILY TILLSHOOT %
* * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *

GRAND MEAN =    35.89

                                                                    ADJUSTED FOR
                                                 ADJUSTED FOR       INDEPENDENTS
                                  UNADJUSTED     INDEPENDENTS       + COVARIATES
VARIABLE + CATEGORY          N    DEV'N   ETA    DEV'N   BETA       DEV'N   BETA

STATE
    1 PREDISTRUBANCE       121     0.56                               1.16
    2 POST DRILLING         22   -11.36                             -11.54
    3 POST BLASTING         52     3.43                               2.18
                                          0.37                               0.36

FAMILY
    1 GR1                  123     1.29                               1.32
    2 GR2                   72    -2.26                              -2.26
                                          0.15                               0.15

AGE
    1 ADULTS                54     1.26                              -0.15
    2 JUVENILE             141    -0.46                               0.06
                                          0.07                               0.01

SEX
    1 MALE                  87    -0.44                              -0.27
    2 FEMALE               108     0.36                               0.21
                                          0.03                               0.02

MULTIPLE R SQUARED                                                         0.357
MULTIPLE R                                                                 0.597
```

Table 3. Analysis of covariance for number of daily movements.

```
* * * * * * * * * * * A N A L Y S I S   O F   V A R I A N C E * * * * * * * * * * *
            MOVEMENT % OF NUMBER OF MOVEMENTS
         BY STATE
            FAMILY
            AGE
            SEX
       WITH MAXTEMP  MAXIMUM TEMPERATURE C
            MINTEMP  MINIMUM TEMPERATURE C
            MEANTEMP MEAN TEMPERATURE C
            DAYLIGHT NUMBER OF MINUTES OF DAYLIGHT
            PRESSURE MEAN DAILY PRESSURE MB
* * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
```

SOURCE OF VARIATION			SUM OF SQUARES	DF	MEAN SQUARE	F	SIGNIF OF F
COVARIATES			784.239	5	156.848	2.322	0.045
MAXTEMP			158.190	1	158.190	2.342	0.128
MINTEMP			2.314	1	2.314	0.034	0.853
MEANTEMP			88.282	1	88.282	1.307	0.255
DAYLIGHT			338.615	1	338.615	5.013	0.026
PRESSURE			144.342	1	144.342	2.137	0.146
MAIN EFFECTS			3425.241	5	685.048	10.142	0.000
STATE			88.994	2	44.497	0.659	0.519
FAMILY			847.590	1	847.590	12.548	0.001
AGE			1009.055	1	1009.055	14.939	0.000
SEX			1839.089	1	1839.089	27.227	0.000
2-WAY INTERACTIONS			520.238	8	65.030	0.963	0.467
STATE	FAMILY		31.737	2	15.868	0.235	0.791
STATE	AGE		195.148	2	97.574	1.445	0.239
STATE	SEX		48.595	2	24.298	0.360	0.698
FAMILY	SEX		54.167	1	54.167	0.802	0.372
AGE	SEX		1.308	1	1.308	0.019	0.889
3-WAY INTERACTIONS			610.684	4	152.671	2.260	0.065
STATE	FAMILY	SEX	524.770	2	262.385	3.885	0.022
STATE	AGE	SEX	115.087	2	57.543	0.852	0.428
EXPLAINED			5340.402	22	242.746	3.594	0.000
RESIDUAL			11617.863	172	67.546		
TOTAL			16958.266	194	87.414		

198 CASES WERE PROCESSED.
3 CASES (1.5 PCT) WERE MISSING.

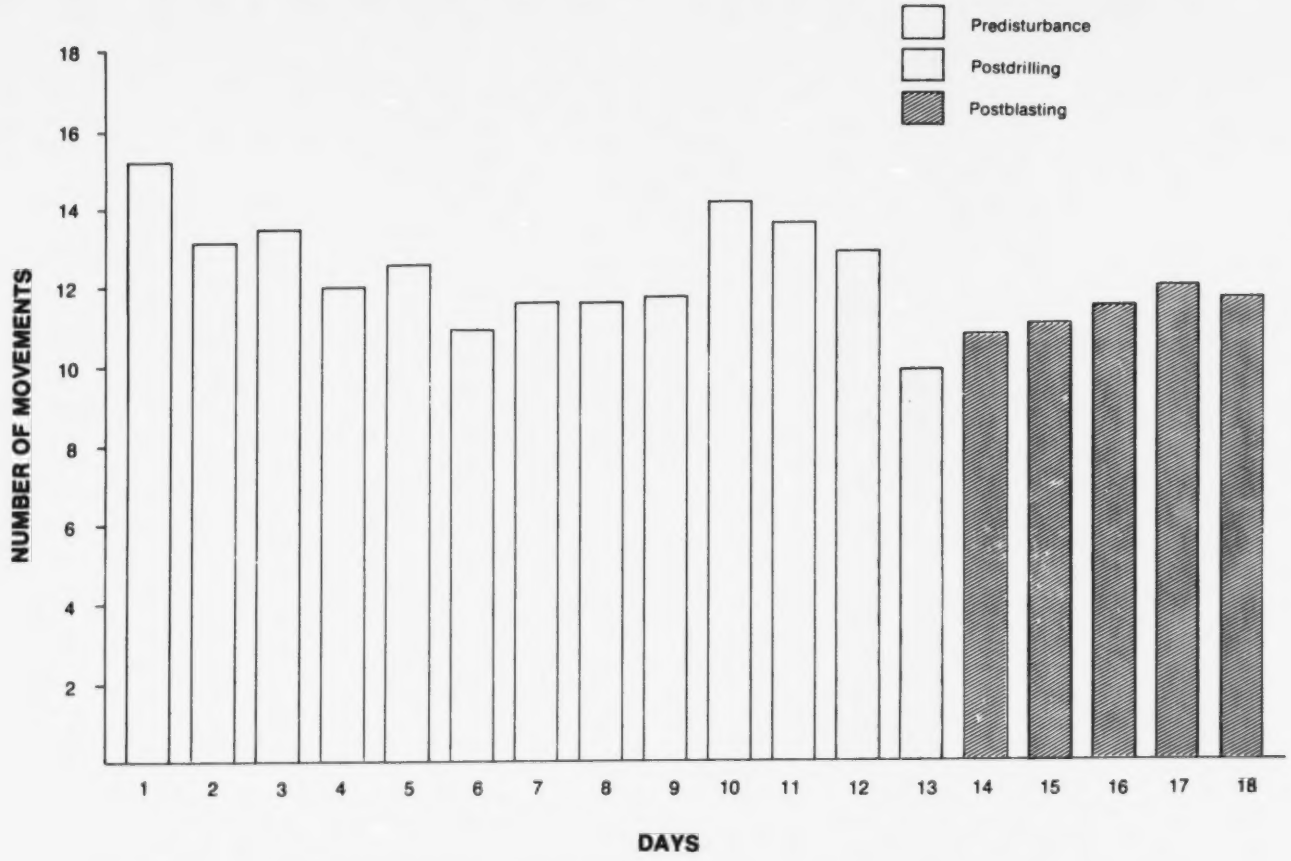


Figure 9: Average number of daily movements for 11 muskrats in relation to period of disturbance.

Table 4. Multiple classification analysis for number of daily movements.

```
***  M U L T I P L E   C L A S S I F I C A T I O N   A N A L Y S I S  ***
          MOVEMENT = # OF NUMBER OF MOVEMENTS
     BY   STATE
          FAMILY
          AGE
          SEX
     WITH MAXTEMP  MAXIMUM TEMPERATURE C
          MINTEMP  MINIMUM TEMPERATURE C
          MEANTEMP MEAN TEMPERATURE C
          DAYLIGHT NUMBER OF MINUTES OF DAYLIGHT
          PRESSURE MEAN DAILY PRESSURE MB
* * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *

GRAND MEAN =    25.77

                                                                ADJUSTED FOR
                                    UNADJUSTED      ADJUSTED FOR  INDEPENDENTS
                                                    INDEPENDENTS  + COVARIATES
VARIABLE + CATEGORY          #    DEV'N   BETA     DEV'N   BETA  DEV'N   BETA

STATE
    1 PREDISTRUBANCE       121     0.94                          -3.99
    2 POST DRILLING         22    -1.45                           3.49
    3 POST BLASTING         52    -1.58                           7.80
                                          0.13                          0.56

FAMILY
    1 GR1                  123     0.68                           1.81
    2 GR2                   72    -1.16                          -3.10
                                          0.19                          0.25

AGE
    1 ADULTS                54    -3.10                          -4.20
    2 JUVENILE             141     1.19                           1.61
                                          0.21                          0.28

SEX
    1 MALE                  87     3.66                           3.46
    2 FEMALE               108    -2.95                          -2.79
                                          0.35                          0.33

MULTIPLE R SQUARED                                                      0.246
MULTIPLE R                                                              0.498
```

4.5 Effects of Seismic Activity on the Use of Pushups and Bank Burrows

MacArthur (1977) suggests that winter survival in cold-adapted muskrats is contingent upon behavioral thermoregulation. This may involve regulating body temperature by adjusting the frequency and duration of pushup and burrow use. Consequently, disturbances which seriously alter their behavior patterns could upset this delicate energy balance and affect the viability of the population. An attempt was made therefore to determine whether dwelling use was altered by disturbances associated with seismic activity.

Patterns of dwelling utilization before and after disturbance were analyzed for Family Groups 1 and 3. Since 3 was removed from the area of intensive disturbance, it serves as a control group. As indicated in Figure 3, Group 1 used 3 burrows and 10 pushups (7 stations). The pushups ranged from 61-119 m to the nearest blast and from 52-125 m to Station 1, the most intensively used burrow. Group 3 used 6 pushups (4 stations) which ranged from 159-189 m to the nearest blast and from 40-149 m to Station 18, the only burrow used by this group. Station 18 was located 204 m from the nearest blast.

4.5.1 Use of Pushups

With respect to possible changes in the pattern of pushup utilization due to disturbance, two alternative hypotheses were examined. The first was that use would decrease in pushups near the disturbance and increase in those farthest away, while the second was that disturbance may cause muskrats to remain near the safety of their burrows and consequently make increased use of the closest pushups.

During data analysis, each category of disturbance was considered an independent treatment. To adjust for missing observations and equipment failures, data was standardized by

means of an activity index based on the number of observations/ number of possible observations x 1000. Linear regression analysis was used to determine whether pushup use was a function of either distance from disturbance or distance from bank burrow. In both cases the significance of the regression was tested, (1) for each period of disturbance and differences between periods and, (2) for the change in use based on the ratio of predisturbance use to postdrilling and postblasting use. Finally, t-tests were used to test for significance of observed changes in use of individual pushups.

4.5.1.1 Relationships with Distance from Disturbance

Results of linear regression analysis indicate that no significant relationship exists between pushup use and distance from the nearest shothole for any of the treatment periods (Table 5). Neither do any of the regressions differ significantly from each other for either Group 1 or Group 3.

This is more clearly shown when the ratio of predisturbance to postdisturbance use is examined as a function of distance. No changes in relative pushup use occur following either drilling or blasting (Table 5). As illustrated in Figure 10 for the combined sample, the slope of the regression line closely approximates 0 ($t = 0.37$, $P > 0.50$), indicating no change in pushup use with distance from disturbance.

Differences in use of individual pushups similarly appear unrelated to distance from disturbance (Table 6). Significant changes were detected in two of seven (29%) stations used by Group 1 while three of four (75%) stations used by Group 3 changed significantly. The average distance of Group 3 pushups from the nearest shot point ($\bar{x} = 176$ m) was substantially greater than in the case of Group 1 ($\bar{x} = 83$ m). No measurable changes occurred from predisturbance to postdrilling. Of the four significant changes between predisturbance and postblasting,

Table 5. Statistical analysis of pushup use regressed on distance to disturbance.

	Regression Equation	Significance			
		Slope		Dif. in Slopes	
		t	Prob.	t	Prob.
FG 1					
Predisturbance	Y = 16.57-0.11X	-0.97	$P > 0.30$	0.55	$P > 0.50$
Postdrilling	Y = 7.68-0.03X	-0.46	$P > 0.50$	0.81	$P > 0.40$
Postblasting	Y = 6.68+0.02X	0.15	$P > 0.50$		
Postdrilling/ Predisturbance	Y = 3.10+0.05X	0.87	$P > 0.40$		
Postblasting/ Predisturbance	Y = 0.72+0.13X	1.28	$P > 0.20$		
FG 3					
Predisturbance	Y = 33.45-0.06X	-0.09	$P > 0.90$	0.21	$P > 0.50$
Postdrilling	Y = 53.72-0.22X	-0.61	$P > 0.50$	0.18	$P > 0.50$
Postblasting	Y = 69.22-0.25X	-0.32	$P > 0.50$		
Postdrilling/ Predisturbance	Y = 36.72-0.17X	-1.37	$P > 0.30$		
Postblasting/ Predisturbance	Y = 88.07-0.42X	-0.88	$P > 0.40$		

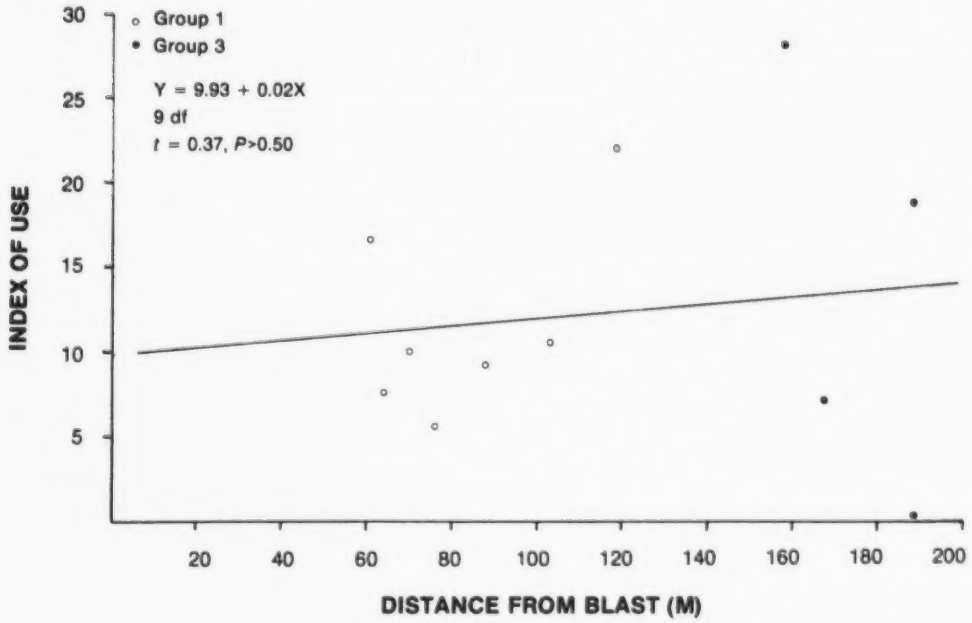


Figure 10: Regression on postblasting: predisturbance pushup activity as a function of distance from the nearest shothole for Family Groups 1 and 3 combined.

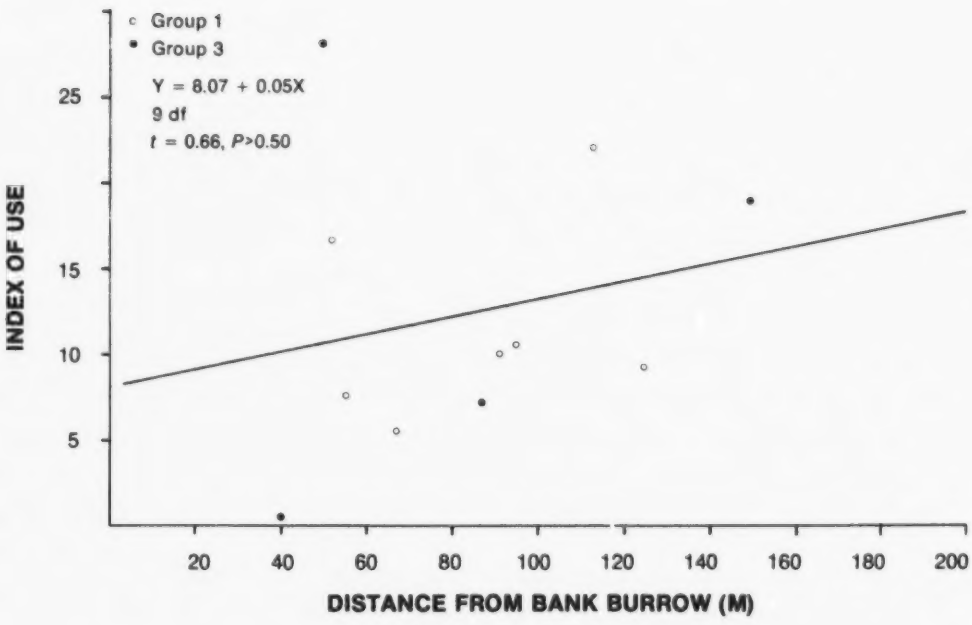


Figure 11: Regression on postblasting: predisturbance pushup activity as a function of distance from the bank burrow for Family Groups 1 and 3 combined.

Table 6. Use of pushups in relation to disturbance, distance from bank burrow and nearest shot point. Bars indicate significant changes ($P < 0.05$).

Stations	Index of Use [1]			Distance	
	Pre-disturbance	Post-drilling	Post-blasting	nearest blast (m)	bank burrow (m)
FG 1					
2	2.11	2.02	3.52	61	52
3	18.64	11.84	14.20	64	55
4	2.27	2.02	2.39	103	95
5	5.96	6.30	13.07	119	113
6	7.37	4.79	4.15	76	67
8	10.70	5.29	10.68	70	91
10	7.98	2.02	7.41	88	125
FG 3					
12	15.19	7.01	0.67	189	40
19	42.83	27.26	30.70	168	87
20	9.72	12.46	27.33	159	50
21	22.33	15.58	42.17	189	149

[1] number of observations/total possible observations x 1000

one pushup showed a decrease in use (PU 12: $t = 2.92$, $P < 0.05$) while the remainder increased (PU 5: $t = 3.85$, $P < 0.01$; PU 20: $t = 6.82$, $P < 0.001$; PU 21: $t = 3.27$, $P < 0.05$).

4.5.1.2 Relationship with Distance from Burrow

Results summarized in Table 7 indicate that use of pushups does not vary with distance from the burrow either before or after drilling and blasting activities. Regression slopes did not differ significantly from 0 or from each other for any of the treatment categories. The hypothesis is again rejected when ratios measuring changes in pushup use are regressed with distance from the burrow (Figure 11).

4.5.2 Use of Burrows

To test the theory that disturbance would cause muskrats to decrease their utilization of nearby burrows and increase the use of burrows farther away from the disturbance, each burrow was tested by analysis of variance. The index of burrow use (number of observations/total possible observations x 1000) was modified to conform to the requirements of ANOVA by means of arc sine transformation.

The results summarized in Table 8 show that all of the burrows used by Group 1 underwent significant changes in daily use with treatment (BB 1: $F = 29.24$, $P < 0.001$; BB 7: $F = 16.84$, $P < 0.001$; BB 9: $F = 4.26$, $P < 0.05$). This change was inversely related to distance from shot holes however; with Station 1, the closest burrow, showing increased use after drilling ($t = 5.51$, $P < 0.001$) and blasting ($t = 10.17$, $P < 0.001$) while use of Stations 7 and 9 decreased after both drilling (BB 7: $t = 6.96$, $P < 0.001$; BB 9: $t = 1.00$, N.S.) and blasting (BB 7: $t = 2.57$, $P < 0.05$; BB 9: $t = 2.64$, $P < 0.05$), It should be noted that use of each burrow in this home range is not strictly independent, since an increase in use of one

Table 7. Statistical analysis of pushup use regressed on distance to bank burrow.

	Regression Equation	Significance			
		Slope		Dif. in Slopes	
		t	Prob.	t	Prob.
FG 1					
Predisturbance	Y = 11.61 - 0.04X	0.51	$P > 0.50$	0	$P = 1.00$
Postdrilling	Y = 8.75 - 0.05X	0.84	$P > 0.40$	0.58	$P > 0.50$
Postblasting	Y = 5.98 + 0.02X	0.31	$P > 0.50$		
Postdrilling/ Predisturbance	Y = 9.68 + 0.03X	0.73	$P > 0.50$		
Postblasting/ Predisturbance	Y = 7.50 + 0.05X	0.57	$P > 0.50$		
FG3					
Predisturbance	Y = 13.61 + 0.11X	0.57	$P > 0.50$	0.18	$P > 0.50$
Postdrilling	Y = 9.84 + 0.07X	0.63	$P > 0.50$	0.75	$P > 0.50$
Postblasting	Y = 1.59 + 0.29X	2.03	$P > 0.10$		
Postdrilling/ Predisturbance	Y = 8.46 - 0.01X	0.19	$P > 0.50$		
Postblasting/ Predisturbance	Y = 9.04 + 0.06X	0.35	$P > 0.50$		

Table 8 Use of bank burrows in relation to disturbance and distance to the nearest shot point. Bars indicate significant changes ($P < 0.05$).

Station	Index of Use[1]			Distance
	Predisturbance	Postdrilling	Postblasting	nearest blast (m)
FG 1				
1	43.63	88.44	75.26	12
7	29.98	17.57	8.29	46
9	15.03	5.09	2.51	20
FG 3				
18	169.56	163.59	144.76	204

[1] number of observations/total possible observations x 1000

burrow is likely to result in decreased use of one or both of the other burrows. In comparison, the amount of time spent in Station 18 by members of Family Group 3 remained essentially unchanged between predisturbance and postdrilling and decreased only slightly after blasting ($F = 3.08$, $P > 0.05$).

4.6 Physical Effects of Seismic Blasting on Muskrats

In 1976 experiments were conducted to determine the extent of blast injury in captive animals exposed to seismic explosions (Westworth 1977). Animals were placed in pushups, simulated bank burrows and under water under a variety of experimental conditions. Both 11.3 and 22.6 kg charges were tested on two study lakes. Post-mortem examinations revealed that the pathological effects were minimal, consisting of hemorrhaging along suture lines in the middle ear and slight lung damage in the form of petechial hemorrhaging. Injury only occurred in animals placed under water 15 m from the shot hole or in artificial burrows. None of the abnormalities found were present in animals not exposed to blasting.

The studies conducted during 1977 provided an opportunity to determine to what extent blast injury occurred under natural conditions among free-ranging animals. Post-mortem examinations were conducted on all radio-marked muskrats following the completion of monitoring on May 3.

The major concern was attempting to ascertain the circumstances involved in the death of three radio-equipped muskrats in Station 14 following the detonation of Shot Hole 1 on April 28. Observations of the blast and the consequent behavior of the muskrats are only partially helpful in this regard. Although some material blew out of the shot hole, the majority of the energy was expended downward and the blast was considered normal. Like several of the other blasts, it caused extensive cracking in the ice, however, in this case water was heard gurgling for a 10 second period at a point 2 m in front of the burrow.

Two days of intensive digging were required to remove the 120 cm of frozen soil covering the dead muskrats. The burrow was vertically stratified containing a number of chambers and passageways (Photo 7). The chambers containing the dead muskrats and the only ones that showed evidence of recent use occurred at the lowest level. Three tagged muskrats, No. 460 471 and 474, were found although 474 did not contain a transmitter. Time did not permit the additional digging necessary to locate #465 although it was presumed to be nearby.

No. 471 and 474 were found in a well-used resting chamber (Photo 8). Smooth ice immediately above and beneath the head of No. 474 (on left in photo) indicated that this animal was in a normal resting location. No. 460 was found in a passageway 1 m away and had evidently been moving toward the chamber containing the other two muskrats at the time of its death. The burrow contained no food items and showed no sign of flooding or structural failure.

All three animals were in good condition prior to death as judged by moderate to abundant subcutaneous fat and the absence of any wounds or lesions. Degenerative changes were minimal since the bodies froze soon after death and remained in that condition until the time of post-mortem examination. Necropsies were performed in the Alberta Veterinary Laboratory in Edmonton on May 18 by Dr. B.E. Beck. The results, which are presented in Appendix I, showed no signs of trauma or other injury that could be associated with pressure changes or vibration caused by blasting.

All surviving radio-marked muskrats were examined in the field immediately after capture. Two of the animals that occupied Station 1 during blasting showed signs of hemorrhaging in the middle ear. No. 452 had moderately severe hemorrhage in the left ear while No. 473 had slight hemorrhage in both ears. In neither case were the tympanic membranes broken. All of

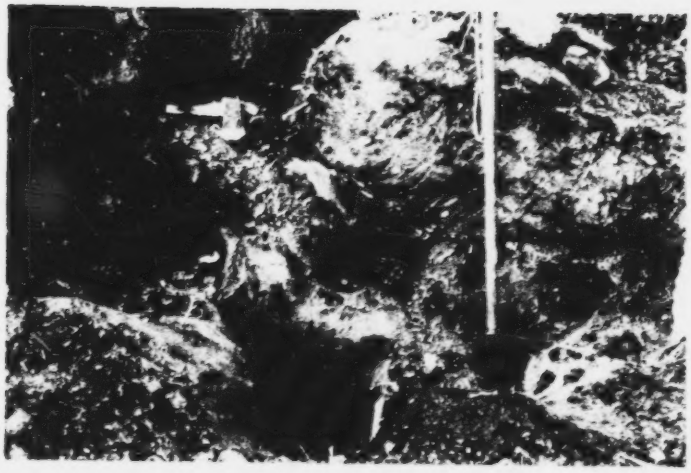


Photo 7. Excavation of bank burrow (Station 14) showing vertical stratification of chambers. Only the lowest chambers were used during late winter.

Photo 8. Two of four muskrats that died in Station 14 after seismic blasting.

the other muskrats were considered normal. Portions of the lungs in most were congested due to post-mortem hypostasis of blood. Adrenal glands were normal in size and weight, indicating no evidence of hypertrophy in the zona fasciculata that was previously demonstrated in stressed muskrats (Westworth 1977).

Because of the technical difficulties involved in placing pressure sensors in muskrat burrows, the observed effects could not be compared with air pressure changes during blasting. Hydrostatic pressure changes were monitored in experiments conducted during 1976 *(ibid.)*, however there was some concern that the methods employed may have underestimated peak pressures through distortion of the amplitude of the initial wave front. The problem was that antialiasing filters modified signals recorded on the seismography by eliminating very high frequencies. A more direct approach involves measuring the amplitude of the peak pressure pulse recorded photographically from a dual beam oscilloscope (Elder and Prudholme 1975). During April 1977, pressure tests using the latter method were conducted by Gulf Canada Ltd. on a physiognomically similar lake (Appendix II). The tests, which covered the full range of experimental conditions examined in this study, showed that underwater pressure changes during seismic blasting on the Delta are extremely small and in the same range as those obtained previously. Maximum recorded values were 0.0115 psi during the peak pressure phase and 0.0125 during the peak rarefaction phase. These low figures apparently explain the absence of pressure injuries in muskrats that were feeding during the period of blasting, including No. 469, which was recorded swimming under water at the time of a blast 120 m away.

5.0 DISCUSSION

The methods employed during the present study enabled us to clearly demonstrate the specific behavioral responses of muskrats to various types of disturbance associated with seismic activity as well as to determine whether disturbance altered long-term patterns of activity. The behavioral reactions of individual muskrats during drilling and blasting are useful in interpreting the results of those parts of the study that considered stress and injury in blast-exposed muskrats. Changes in activity patterns have more significance when one is considering factors that may affect strategies for long-term winter survival or reproduction.

The results of both types of observations are in agreement. In terms of the immediate response of muskrats to drilling, it was apparent that only the operation of the helicopter could be considered disruptive. Moreover, muskrats did not react to drilling activities centered 60 m or more from burrows or pushups. Analysis of the variation in activity (feeding) patterns indicated that while activity levels changed significantly with seismic activity, these changes were limited to the two day period between drilling and blasting. The proportion of time spent feeding and resting, the number of daily movements and diel activity rhythms remained essentially the same during the predisturbance and postblasting periods.

In discussing the observed effects of drilling activity it should be noted that the experimental conditions were not strictly typical for, although helidrills are widely used in remote areas, the majority of seismic exploration on the Mackenzie Delta employs tracked vehicles. The effects attributed to helicopter disturbance therefore, would not be encountered in conventional operations. The extent of any possible added effects due to the movement and operation of tracked surface vehicles cannot be judged from this study.

Detonation of the blasts had a dichotomous effect. Detonation of 11.3 kg charges had no effect when burrows were located 60 m or more from shotholes and elicited only a temporary response at a distance of approximately 12 m. A 6.8 kg charge however, led to the death of four muskrats when it was exploded in a shothole located 12 m from Station 14.

The latter results conflict with all of our previous findings. It is also unusual since careful post-mortem examination of the dead muskrats failed to show any evidence of blast injury. Traumatic lesions that are normally associated with excessive air or water pressure changes or ground movement (Rausch 1973, Chiffelle *et al.* 1968, White *et al.* 1970), or that occurred to a minor extent in some of our earlier experiments (Westworth 1977), were clearly not present in this case.

The absence of pathological findings along with observations recorded at the time of this blast suggest two possible explanations. Death could be caused by a change in chemical composition of air in the burrow or it could have been attributed directly to noise generated by the explosion.

It has been known since 1927 that particular genetic strains of animals react abnormally to loud noises through a phenomenon known as audiogenic seizure. This apparently occurs when intense noise stimulates the sympathetic nervous system inducing changes that include convulsions, post-convulsive bradycardia, decreased norepinephrine levels and, in some cases, death due to respiratory failure preceeding heart failure (Lehman 1970). Audiogenic seizure has been described in rabbits, chickens, dogs and goats but has been most frequently observed and studied in various species of rodents. In most cases it follows the same pattern with animals exposed to loud noise displaying a startle reaction followed by a latent period lasting from less than a second to several minutes after which the animals run wildly in a disoriented manner

before entering a state of clonic convulsion (Lehman and Busnel 1963). In cases where the convulsions end in death, the animal typically dies with its eyes closed and its legs extended (*ibid.*).

To a certain extent, observations recorded at the time of the blast fit the above description. 'No. 471 reacted suddenly to the shot, then began moving rapidly around in the burrow.' No. 465 also began moving around but was stationary for one minute immediately after the blast. Five minutes after the blast both animals were stationary and are presumed to have been dead. Similarly, the positions of the dead muskrats do not rule out audiogenic seizure. While the legs were not completely extended, in none of the victims were they tucked under the body in the normal sleeping posture (Photo 6). In each case the eyes were closed.

While these observations prevent us from rejecting the possibility of audiogenic seizure we regard it as being extremely unlikely. One reason is that it is rarely observed in wild animals and has never been reported in muskrats. Since it is apparently associated with genetic abnormalities of the nervous system it is unlikely that it would have a uniform effect on four members of a wild population even though they are thought to be members of the same family group. A second reason is that the sound intensity of the blast is not thought to be within the 90-124 dB range reported necessary to cause audiogenic seizure (Lehman and Busnel 1903). Sound levels were not recorded during the study, but observers stationed at the burrow during the blast reported no extreme discomfort (In terms of human response to sound pressure levels caused by blasting the threshold of pain occurs at approximately 120 dB (Bollinger 1971)). They were judged substantially lower than the noise levels reported for a pile driver (101 dB) or a train whistle (106 dB) at an equivalent distance (Quarles 1974). The sound was also substantially less than in the case

of SH 3 which completely blew out. It is not known to what extent the sound would be attenuated in the burrow.

Some of the observations also support the theory that a change in the gaseous composition of the burrow resulted in death of these muskrats. Water was heard bubbling under the ice in-front of the burrow for 10 seconds following the blast. This may have resulted from gas being expelled through a fisure in the substrate created by the explosion. Toxic gases could originate from two sources.

Geogel, the explosive used in the experiment and the one normally employed in on-shore seismic work, is in "fume class 2" which prohibits its use in enclosed areas such as underground mines. When Geogel explodes, it releases carbon dioxide, nitrogen, water vapour, carbon monoxide and certain nitrous oxides (J. Harbourne pers. comm.). The latter two compounds are toxic, although carbon monoxide is by far the more lethal of the two. Post-mortem effects normally associated with CO poisoning, such as cyanosis and discoloration of the blood, were not evident in any of the dead muskrats (B. Beck pers. comm.).

The second possibility is that a naturally occurring pocket of methane was fractured by the explosion, releasing gas into the burrow. Shallow deposits of natural gas are apparently common in the Delta and are commonly released when drilling seismic shotholes (B. Elder, J. Cooper, J. Harbourne pers. comm.). The development of methane deposits in gas-domed mounds in the Mackenzie Delta area has been described by Mackay (1965). During our pushup surveys, pushups were occasionally encountered that contained marsh gas or methane under pressure. On one occasion one of my technicians ignited the gas released through the 1 cm diameter hole made by a pushup probe. The clear blue flame burned for an estimated period of two minutes at a height of greater than 0.5 m. The gas is a

product of anaerobic decomposition of organic matter and is usually associated with lesser amounts of other gases, in some cases including hydrogen sulfide.

Methane itself is a colorless, odorless, non-toxic gas of low anaesthetic potency (Gosselin *et al.* 1976). It affects animals by depressing the respiratory centres and could, by displacing air in the burrow, cause death through anoxia. This condition is difficult to detect and would not be apparent in frozen specimens (B. Beck pers. comm.). H_2S, on the other hand, is toxic, causing damage to the bronchii, inflamation and edema of the lungs. These changes however, are not specific to H_2S and would be disguised by the effects of dehydration and ice crystal formation in the lungs of frozen animals (T. Shnitka pers. comm.). The characteristic odour associated with H_2S was not detected at the time of the blast or during excavation of the burrow.

There was some concern in previous investigations that muskrats swimming underwater at the time of seismic blasts would be especially prone to suffering injury through hydrostatic pressure changes. The results during 1976, when muskrats were experimentally exposed to blasts, as well as the observation of a free-swimming muskrat during blasts in 1977 however, indicated that blast effects were not significant. There findings are supported by the extremely small pressure changes observed (max. 0.027 psi for 11.3 kg charge 18.3 m from shore). These pressures are far below those shown in the literature to cause serious injury or death. For example, rabbits are reported to survive peak blast pressures of 65 - 250 psi when immersed 1.4 m underwater and 280 - 940 psi when floating on the surface, although the effects included lung hemorrhages, edema and hyperemia of intestines (Clemedson 1948 cited in Altman and Dittmer 1966). It is apparent that the rapid attenuation of compressional waves as the pressure pulse passes through the range of interfaces and media of widely varying accoustic

impedance (eg. frozen silt - soft lake bottom - water) encountered on the Delta, results in hydrostatic pressure changes well below the level necessary to cause serious injury even with charges as high as 22 kg.

Pushup surveys conducted during 1976 demonstrated essentially no change in the overall proportion of active pushups on seismic and control lakes after seismic activity. Within some of the individual lakes however, the proportion of active pushups increased at distances greater than 180 m from seismic lines. The present study provided the opportunity to examine in more detail the relationship between use of dwellings by muskrats and distance from disturbance. The results showed that neither proximity to seismic shotholes nor proximity to burrows significantly affected use of pushups by muskrats. Of particular interest were the changes in burrow use by muskrats in Family Group 1. As previously explained, the seven radio-marked muskrats in this family group made use of three burrows that ranged in distance from 12 to 46 m to the nearest shot point. Use of the most distant burrows decreased with disturbance however, while the closest burrow demonstrated a highly significant increase in use ($P < 0.001$). These results clearly indicate that neither drilling nor blasting elicit an avoidance response by muskrats and support the overall conclusion that seismic activity has no major, long-lasting effect on the activity or behavior of muskrats.

6.0 CONCLUSIONS AND RECOMMENDATIONS

The foregoing results support the tentative conclusion reached during the first year of the study, that seismic exploration practices as they now exist do not pose a significant threat to muskrat populations on the Mackenzie Delta. On the basis of research conducted during 1976 and 1977, the following specific conclusions can be drawn:

(a) The low instantaneous pressure changes experienced in delta lakes during seismic blasting at distances of more than 12 m from the lake perimeter are not sufficient to cause substantive injury or death.

(b) Disturbance associated with seismic exploration does not result in measurable increases in physiological stress or lowered reproductive performance.

(c) Disturbance associated with seismic exploration does not have long-lasting effects on muskrat behavior or activity patterns.

(d) Small numbers of pushups are destroyed through compaction by heavy equipment during lake crossings, however, use of pushups and burrows not destroyed in this manner appears to be unrelated to distance from seismic shot holes.

The above conclusions are subject to some qualification however, as a result of the mortality of 3 of 19 radiomarked muskrats observed during the present study. This mortality, which occurred as a probable effect of infiltration of natural methane gas into a burrow, indirectly resulted from a seismic explosion. The probability of similar events occurring during normal seismic operations is not known; shallow methane deposits are apparently of common occurrence on the Delta but the likelihood of these deposits occurring close to muskrat burrows which in turn are in close proximity to seismic shotholes may be quite remote.

Presently, land use permits issued for seismic exploration prohibit blasting within 12.2 m (40 ft) of waterbodies. On the basis of the findings of this study, the author believes that this requirement provides a reasonable degree of protection to muskrat populations. Although the possibility of mortality through exposure to methane deposits might be lessened by increasing this interval, existing information does not provide a scientific basis for recommending changes.

Although it seems unlikely that pushup destruction during lake crossings by seismic equipment would result in direct mortality of muskrats, it does alter the feeding patterns of muskrats and may ultimately reduce survival potentialities of affected family groups. To minimize the adverse effects of pushup loss on muskrats and the potential disruption of trapping activities, seismic operators should avoid pushup concentrations during lake crossings. To facilitate this, maps showing the location of proposed seismic lines should be presented to local trapper groups or publicly displayed well in advance of intended starting dates, to enable trappers to mark the pushups on lakes they intend to trap. This is not viewed as a major inconvenience to trappers since many delta trappers habitually mark pushups prior to the period of heavy snow accumulation in late winter.

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Cooper, J. Imperial Oil Ltd., Calgary, Alberta.

Elder, W. Gulf Oil Canada Ltd., Calgary, Alberta.

Harbourne, J. Canadian Industries Ltd. Calgary, Alberta

Shnitka, Dr. T. Acting Chairman, Department of Pathology, Univ. of Alberta, Edmonton.

APPENDIX I

PATHOLOGICAL REPORT

Alberta
AGRICULTURE
VETERINARY SERVICES DIVISION

LABORATORY SERVICES
LONGMAN LABORATORY BUILDING
BOX 8070
EDMONTON, ALBERTA T6H 4P2

BOX 197
FAIRVIEW, ALBERTA T0H 1L0

BOX 177
LETHBRIDGE, ALBERTA T1J 3Y5

OWNER

Dave Westworth,
10178 - 89 Street,
Edmonton, Alberta.

Submitted by ..... same

Nature of Specimen ..... Three dead muskrat

Laboratory Report: Specimen No. A77-3783 B Date ..... July 20, 1977

Please excuse the delay in the completion of this examination. I have just finished the histologic examination of the brain and I have been unable to find evidence of hemorrhage associated with trauma, contusion, or change in pressure. Unfortunately, due to freezing artifact many red blood cells have been hemolyzed. However, some of the brains have been well preserved and I can find no lesions that would be associated with trauma.

The identification of the liver parasitic cysts is included.

In conclusion, I have been unable to determine any significant lesions in these muskrats that would explain the cause of their death.

B/EC

B.E. Beck, D.V.M.
Head, Animal Disease Section.

Alberta AGRICULTURE

VETERINARY SERVICES DIVISION
Laboratory Services

Form V.L.-1

DATE REC'D. May 18,1977

PATH No. A77-3783 B

VETERINARIAN

SUBMITTED BY:

OWNER

Dave Westworth
10178 -89 Street
Edmonton, Alberta

429-2958

SPECIMEN: 3 DEAD MUSKRAT

HISTORY: Muskrats from McKenzie Delta.
Suspected to be killed by an explosion.

POST MORTEM LESIONS:
These are post mortems on three muskrats. The muskrats are identified as following: Muskrat #1 is identifed as #460 - weight 675 grams - Station 14 (BB3 Lake End - McKenzie Delta - May 1,1977. Muskrat #2 is number 471- both of these muskrats have transmittors in the peritoneal cavity. Muskrat #1 was found dead in the runway. Muskrats #2 and #3 were found dead in the burrow. Muskrat #3 is identified as #474 - 800 grams and was found dead in its bed.
Post mortem examination showed hypostatic congestion on the lateral basis of the lungs and several isolated lobes of the lung demonstrated hypostatic congestion. Muskrat #1 has extensive hydatid cysts in the liver probably tapeworm cysts. There is no evidence of hemorrhage into the tympanic bullae - all ear drums are intact. There is no external lesions. Hemorrhages, contusions, or fractures not evident in the carcass. The liver and lungs are saved in the freezer pending further analysis - selected tissues and brain to HISTOPATHOLOGY for sectioning.

B.E. Beck, D.V.M.
Head, Animal Disease Section.

July 20, 1977

DIAGNOSIS:

SIGNED:

APPENDIX II

RESULTS OF HYDROSTATIC PRESSURE TESTS

January 3, 1978

Pressure Studies Conducted in the
MacKenzie Delta During April of 1977

During three days in April of 1977 pressure studies were carried out in an unnamed lake located at 68° 24' 45" N and 133° 48' W in the MacKenzie Delta. The lake was reached by driving north along the East Channel some 6.7 kilometers from Inuvik's River Road.

Bill Elder and myself, from Gulf Canada; John Cooper, from Imperial; and Doug Ross, from Teledyne Exploration conducted the pressure tests.

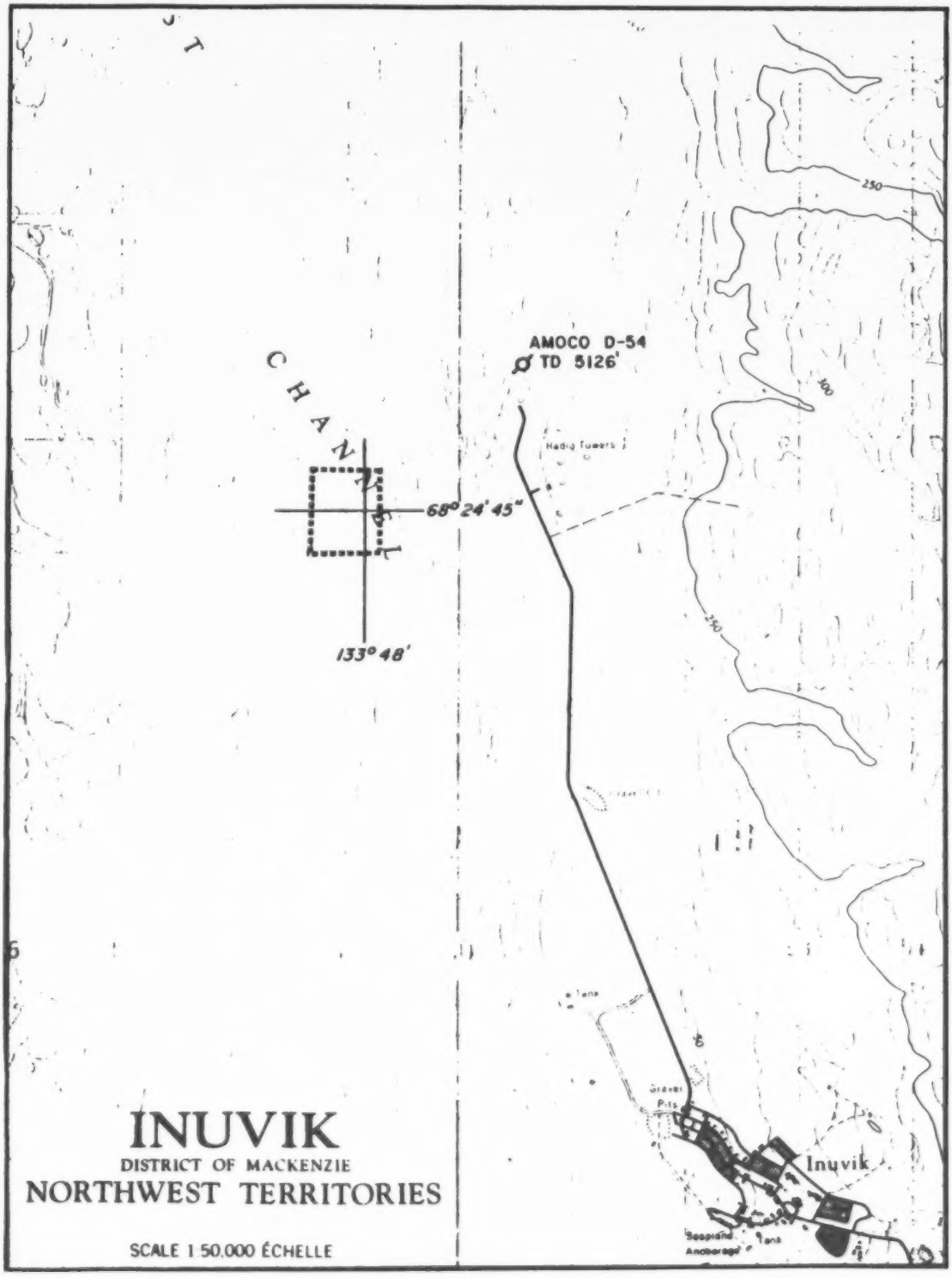
Equipment chosen for these tests included a Tectronics Model 453 dual beam oscilloscope with a Polaroid Model C-30 camera attached, and a KSP Industries Model UT-102 hydrophone. The UT-102 hydrophone has a uniform response over a frequency range of 17Hz to 14KHz. The hydrophone was equipped with 100 feet of coaxial cable and then calibrated by the manufacturers. The calibration sheet is attached.

A seismic shot hole rig drilled 60 foot deep holes along the lake shore and loaded these holes with 60% geogel dynamite charges ranging from 5# to 60#. The holes were drilled 40' and 26' back from the lake edge, totally in a silty-clay.

The hydrophone was placed in the lake water at various positions from 400' to 20' from the lake edge and at depths of 33" to 72" beneath the surface of the ice. Ice thickness ranged from 18" to 33".

The charges were detonated and the resulting pressures in the water were monitored. These pressures ranged from 0.0004 P.S.I. to 0.0125 P.S.I. and were repeatable values. The velocities calculated from the arrival times of the peak pressure pulse (attached table of values) were reasonable and compares with velocities observed from seismic data shot in the same area.

A.R. Fink


AMOCO D-54
TD 5126'
68° 24' 45"
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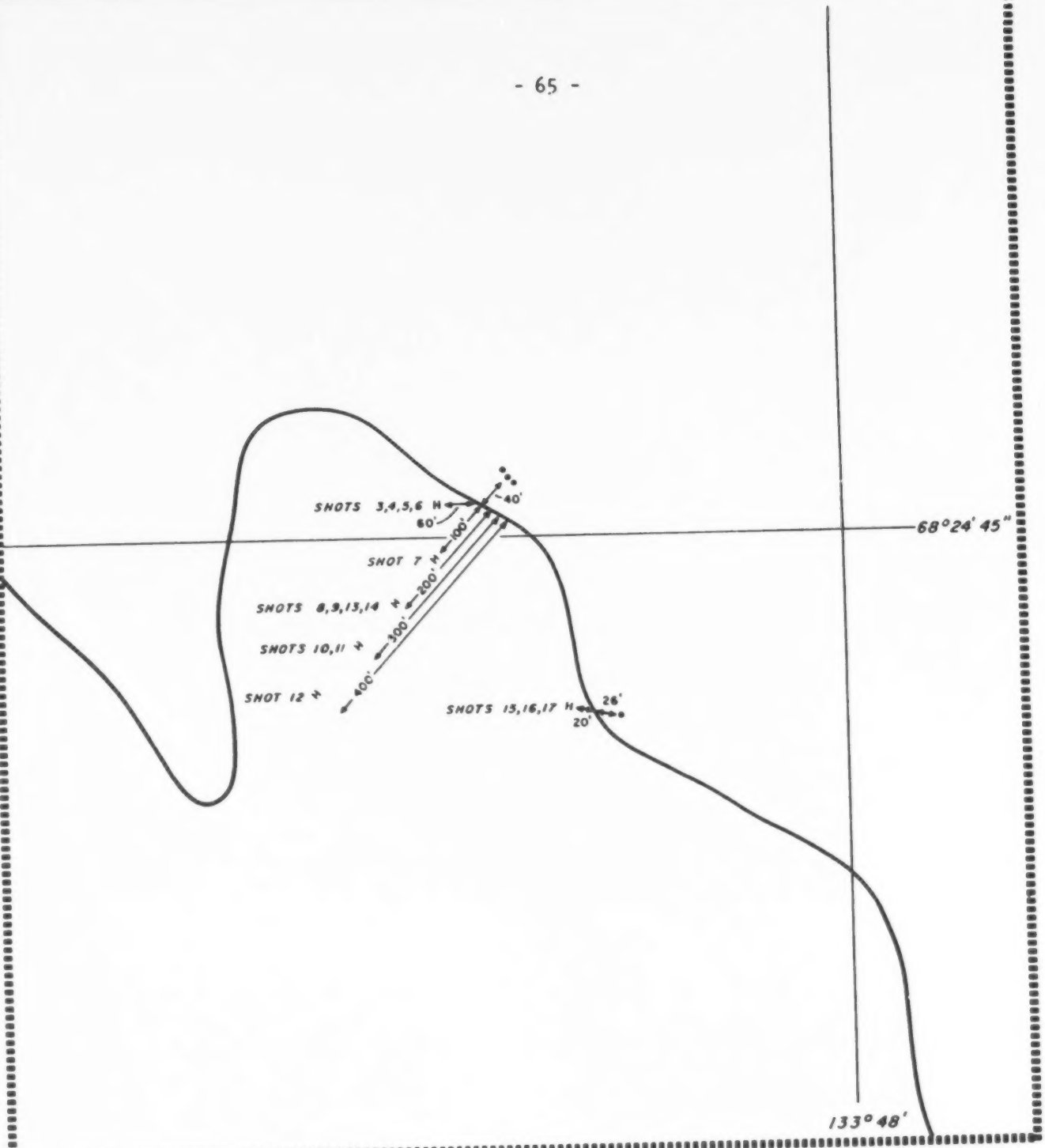
INUVIK
DISTRICT OF MACKENZIE
NORTHWEST TERRITORIES
SCALE 1 50,000 ÉCHELLE



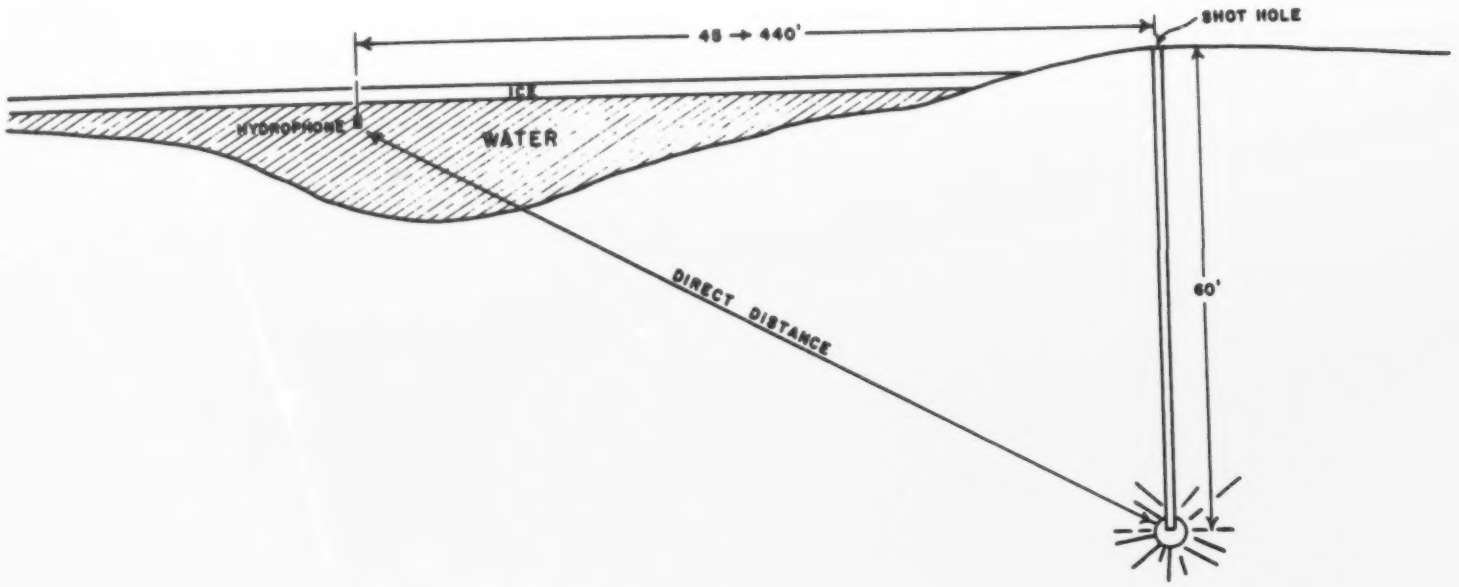
GULF OIL CANADA LIMITED

MACKENZIE DELTA

PRESSURE STUDY SET-UP

• SHOT HOLE
H HYDROPHONE

JUNE, 1977

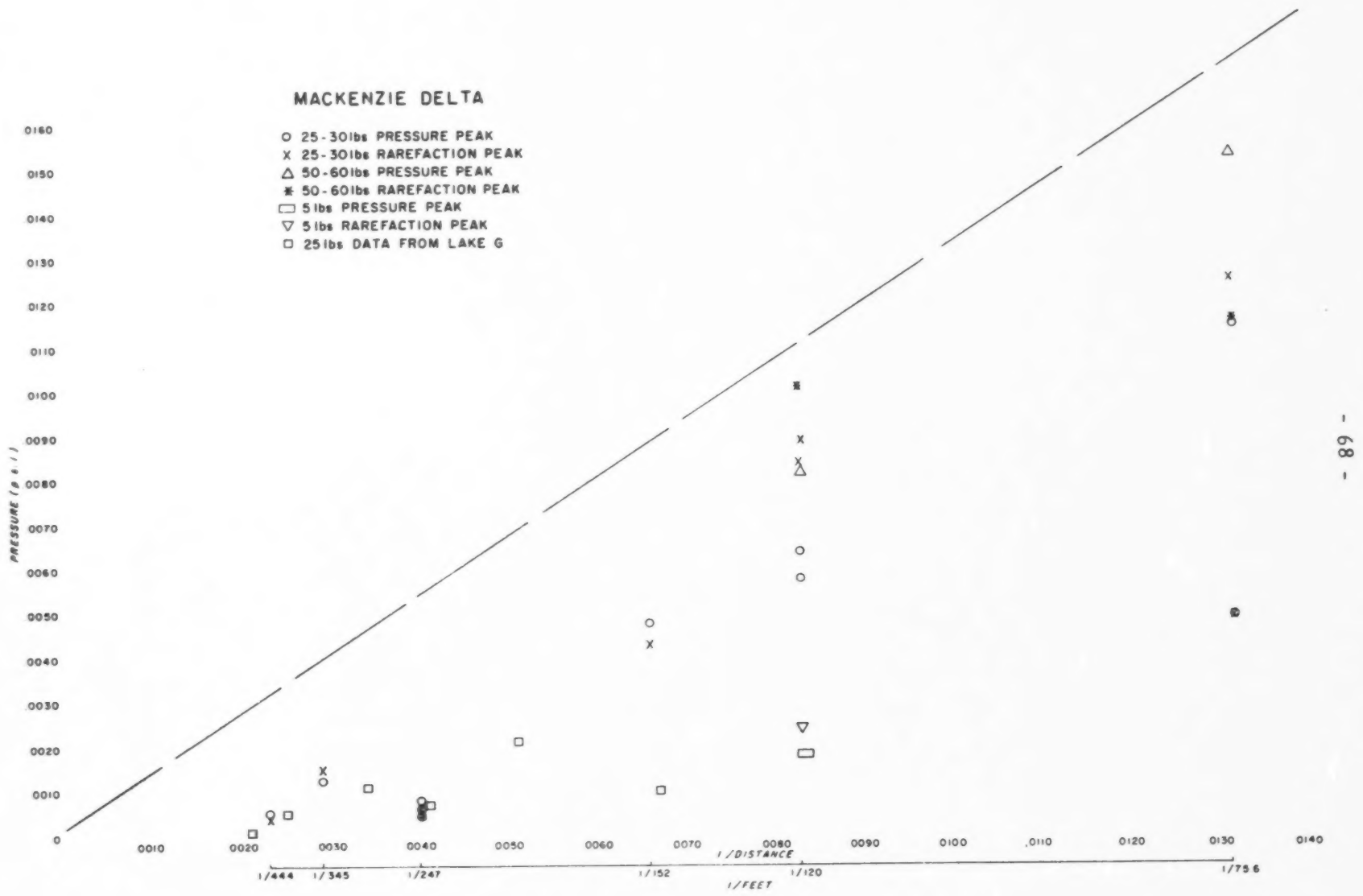


GULF OIL CANADA LIMITED

MACKENZIE DELTA PRESSURE STUDY

DATE: JUNE 1977

SHOT #	CHARGE SIZE	PEAK PRESSURE		PEAK RAREFACTION		DIRECT DISTANCE		UP-HOLE TIME TO PEAK PRESSURE PULSE	VELOCITY
		VOLTS	@.24V/P.S.I P.S.I	VOLTS	@.24V/P.S.I P.S.I	DIST.	1/DIST	(millisec.)	DIST./E.H.T. (ft./sec/)
3	5# @ 60'	.0075	.0018	.010	.0024	120	.0083	22	5460
4	25# @ 60'	.027	.0064	.037	.0089	120	.0083	22	5460
5	25# @ 60'	.024	.0058	.035	.0084	120	.0083	22	5460
6	50# @ 60'	.034	.0082	.042	.0101	120	.0083	22	5460
7	25# @ 60'	.020	.0048	.018	.0043	152	.0066	30	5077
8	25# @ 60'	.0035	.0008	.0025	.0006	247	.0040	55	4498
9	25# @ 60'	.0020	.0005	.0024	.0005	247	.0040	55	4498
10	25# @ 60'					345	.0029		
11	25# @ 60'	.0055	.0013	.0062	.0015	345	.0029	80	4316
12	25# @ 60'	.0024	.0005	.0018	.0004	444	.0023	95	4675
13	30# @ 60'	.0024	.0005	.0028	.0007	247	.0040	35	6185
14	25# @ 60'	.0026	.0006	.0020	.0005	247	.0040	40	6185
15	30# @ 60'	.048	.0115	.052	.0125	76	.0132	40	5040
16	25# @ 60'	.020	.0048	.020	.0048	76	.0132	15	5040
17	60# @ 60'	.064	.0154	.048	.0115	76	.0132	15	5040


MACKENZIE DELTA
○ 25-30lbs PRESSURE PEAK
X 25-30lbs RAREFACTION PEAK
△ 50-60lbs PRESSURE PEAK
✱ 50-60lbs RAREFACTION PEAK
▭ 5lbs PRESSURE PEAK
▽ 5lbs RAREFACTION PEAK
□ 25lbs DATA FROM LAKE G
PRESSURE (p.s.i.)
0160
0150
0140
0130
0120
0110
0100
0090
0080
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1/120
1/75.6
1/FEET
-68-

POOR

QUALITY

ORIGINAL